Institut für Tierwissenschaften
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# Nutrition of giraffes (*Giraffa camelopardalis*) in captivity: Evaluation of feeding practice and analysis of rations in European zoos

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“I am a giraffe, I am about that space a little above the blade, and my bodily intent is to be elevated above all other living things, in defiance of gravity.”

“Giraffe” by J.M. Ledgard

## SUMMARY

**Nutrition of giraffes (*Giraffa camelopardalis*) in captivity: Evaluation of feeding practice and analysis of rations in European zoos**

Compared to other zoo herbivores, the nutrition of captive giraffes is particularly challenging. They belong to the group of browsing ruminants and developed adaptations which enable optimal ingestion, comminution and digestion of browse as preferred plant material. Because browse as natural forage is restrictedly available in zoos, rations are composed of compensatory feeds, which resemble browse to different degrees and need to be combined in a most convenient way. Feeding recommendations provide appropriate feeding schedules for captive giraffes. Nevertheless, feeding practice in zoos is affected by disunity, and certain nutrition-related phenomena and diseases occur in captive giraffes. Beyond the findings from prior studies on the nutrition of browsing ruminants, it is necessary to evaluate how ration composition affects captive giraffes and whether findings reveal further space for improvement in the nutrition of giraffes in zoos.

In this study, two sources of information were used. First, a survey was conducted in zoos of the European Endangered Species Program of the giraffe to gain comprehensive knowledge on current giraffe feeding practice and its potential variability. Results were analysed focusing on developments in practical feeding during the past decade and on concordance with recommendations. Secondly, documentation periods were executed in twelve German zoos, during which data on ration composition and quality of feedstuffs were generated. Together with additional data on different animal variables, which are known to indicate suitability of feeding, the results were supposed to give insight into the impact of different rations on captive giraffes.

Results revealed considerable variation in feeding practice and some deviation from recommendations in approximately 50% of the zoos. Improvement was particularly possible concerning ration composition, as concentrate feeds and produce (fruits and vegetable) regularly accounted for > 50% of daily dry matter (DM) intake, resulting in a limited intake of forage. Recommendations on preferable forage (lucerne hay) and non-forage feeds (pelleted compound feeds, dehydrated lucerne pellets, unmolassed sugar beet pulp) were confirmed with regard to chemical composition and fermentative characteristics. However, especially with the choice of non-forage feeds, 'traditional' starch-based commodities were widely preferred over recommended, more adequate feedstuffs for ruminants. Abandoning produce from giraffe rations was clearly confirmed and supported based on the negative impact of produce on DM and forage intake.

As increasing proportions of concentrate and greater dietary energy content lowered DM intake, an energy-related DM intake regulation was assumed in the captive giraffes. Consequently, less DM as possible from gut capacity was ingested, at the expense of forage which was offered for *ad libitum* intake. This also led to adverse effects on the behaviour pattern of the giraffes. Increasing consumption of forage resulted in more time that was spent with forage intake activity and less occurrence of oral stereotypies during observation periods.

In conclusion, the adjustment, most likely reduction of amounts of concentrate feeds and produce in the ration is a precondition to realise the desired high forage intake in captive giraffes. A continuing communication and discussion of feeding recommendations and particularly their practicability may lead to a more widespread and consistent application and thus improvement of giraffe feeding practice in European zoos.

## ZUSAMMENFASSUNG


**Studien zur Ernährung von Giraffen (*Giraffa camelopardalis*) in Zoohaltung: Bewertung der Fütterungspraxis und Charakterisierung von Rationen aus europäischen Zoos**

Die Ernährung von Giraffen im Zoo stellt im Vergleich mit anderen Pflanzenfressern eine besondere Herausforderung dar. Giraffen sind Laub fressende Wiederkäuer und haben Anpassungen entwickelt, die eine optimale Aufnahme, Zerkleinerung und Verdauung von Laub als bevorzugter Nahrung ermöglichen. Unter Zoobedingungen ist Laubfütterung nur begrenzt möglich. Rationen enthalten deshalb vor allem Futtermittel, die den Eigenschaften von Laub in unterschiedlichem Ausmaß ähneln, was eine passende Kombination in der Rationsgestaltung erfordert. Fütterungsempfehlungen geben Hilfestellung bei der Realisierung einer artgerechten Fütterung, jedoch zeigen sich in der Praxis Unterschiede in der Akzeptanz der Empfehlungen. Auch bestimmte Anzeichen und Erkrankungen bei Zoogiraffen weisen darauf hin, dass die Fütterung nicht immer der guten fachlichen Praxis entspricht. Über den vorhandenen Wissensstand hinaus galt es deshalb herauszufinden, welche Auswirkungen unterschiedliche Rationen auf Giraffen in Zoos haben, und ob sich daraus Verbesserungspotential für die Fütterung erschließt.

Datengrundlage dieser Studie war zum einen eine Umfrage unter den Mitgliedszoos des Europäischen Erhaltungszuchtprogramms für Giraffen. Der Stand der Fütterungspraxis wurde erfragt und Unterschiede zwischen den Zoos, generelle Entwicklungen der letzten zehn Jahre und der Grad der Übereinstimmung mit den Fütterungsempfehlungen evaluiert. Zum anderen wurden in zwölf deutschen Zoos Daten zur Rationszusammensetzung und Futtermittelqualität erhoben. Die Ergebnisse wurden zusammen mit zusätzlich generierten Daten zu ernährungsspezifischen Tiervariablen genutzt, um Erkenntnisse über die Auswirkungen der Rationsgestaltung auf Giraffen zu gewinnen.

Die Ergebnisse zeigten eine ausgeprägte Variabilität der Fütterungspraxis, mit Abweichungen von den Empfehlungen in 50 % der Zoos. Verbesserungspotential wurde insbesondere bei der Rationszusammensetzung deutlich. Der Anteil an Konzentrat- und Saftfutter in der Trockenmasse (TM) der Ration betrug regelmäßig mehr als 50 %, was mit einem entsprechend geringen Grobfutteranteil einherging. Fütterungsempfehlungen für Luzerneheu als Grobfutter sowie eine Ergänzung mit pelletiertem Mischfutter, Luzernegrünmehlpellets und Zuckerrübenschnitzeln konnten bestätigt werden. Dennoch zeigte sich besonders bei der

Auswahl von Konzentratfutter eine Präferenz für ‚traditionelle' stärkereiche Getreideprodukte, trotz ihrer wegen eines sehr raschen ruminalen Abbaus begrenzten Eignung für Wiederkäuer. Die Empfehlung auf Saftfutter zu verzichten, konnte angesichts negativer Auswirkungen auf die Futteraufnahme nur bestätigt und unterstützt werden.

Da steigende Konzentratfutteranteile bzw. Energiegehalte in der Ration mit einer abnehmenden TM-Aufnahme der Giraffen verbunden waren, wurde die Regulation der TM-Aufnahme mit besonderem Interesse betrachtet. Eine energiebasierte Futteraufnahmeregulierung wurde angenommen, weil die Giraffen weniger Futter, vor allem Grobfutter, aufgenommen haben als es die Kapazität des Verdauungstrakts erlauben würde. Dies hatte auch Auswirkungen auf das Verhaltensrepertoire der Giraffen. Je höher der Grobfutteranteil der Rationen war, umso mehr Zeit wurde mit Futteraufnahmeaktivität verbracht und desto weniger orale Stereotypien zeigten sich im Beobachtungszeitraum.

Es wurde geschlussfolgert, dass eine Anpassung, in der Regel eine Reduzierung der Konzentrat- und Saftfuttermengen Voraussetzung für eine möglichst hohe Grobfutteraufnahme bei Zoogiraffen ist. Der intensive Austausch über die Praxistauglichkeit von Fütterungsempfehlungen könnte die Bereitschaft zur Umsetzung steigern und so eine Verbesserung der Giraffenernährung in europäischen Zoos ermöglichen.

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## ABBREVIATIONS

| | |
|---|---|
| ac. | Activity |
| ADFom | Acid detergent fibre expressed exclusive of residual ash |
| $ADIA_{Faeces}$ | Acid detergent insoluble ash in faeces |
| $ADIA_{Feed}$ | Acid detergent insoluble ash in feed |
| ADL | Acid detergent lignin |
| aNDFom | Neutral detergent fibre assayed with heat stable amylase and expressed exclusive of residual ash |
| a.p. | Ante partum |
| BCS | Body condition score |
| BW | Body weight |
| CF | Crude fat |
| CP | Crude protein |
| d | Day |
| DM | Dry matter |
| DMI | Dry matter intake |
| EAZA | European Association of Zoos and Aquaria |
| EEP | European Endangered Species Program |
| f | Female |
| FC ratio | Forage to concentrate-ratio |
| GIT | Gastrointestinal tract |
| h | Hours |
| IFA | Index of feeding appropriateness |
| kg $BW^{0.75}$ | Metabolic body size |
| Ls mean | Least squares mean |

| | |
|---|---|
| GP | Gas production from 200 mg substrate (DM) |
| m | Male |
| max. | Maximum |
| ME | Metabolisable energy |
| MEI | Metabolisable energy intake |
| min. | Minimum |
| MJ | Megajoule |
| n.a. | Not available |
| n.c. | Not considered |
| OM | Organic matter |
| PEG | Polyethylene glycol |
| p.p. | Post partum |
| RNB | Ruminal nitrogen balance |
| SD | Standard deviation |
| SE | Standard error |
| WAPS | Weighted average particle size |

# CHAPTER 1

## General introduction

Giraffes (*Giraffa camelopardalis*) are popular, in the truest sense of the word outstanding wild animals being kept in numerous zoos in Europe. Almost all giraffe facilities are joined in the European Endangered Species Program (EEP) for the giraffe, among which increasing numbers of animals were registered during the last decade (Jebram, 2012). Nevertheless, giraffes belong to that group of ruminants, whose husbandry and in particular nutrition poses challenges. Ruminants are differentiated according to their feeding type with preference for grasses or for browse. Giraffes are classified as comparatively little selective, but strictly browsing ruminants (Van Soest, 1988; Hofmann, 1989; Steuer et al., 2014), foraging for dicotyledonous plant material from trees and shrubs. This becomes an issue in captivity, where the availability of browse is limited due to seasonal fluctuation and management aspects, and necessarily there is need to provide suitable compensatory feeds to browsing ruminants like the giraffe.

Like all ruminants, giraffes have a demand for structural fibre, and the provision of forage-based rations is advantageous to maintain ruminal function and animal health (Van Soest, 1994; Jung and Allen, 1995). However, browse as natural forage shows different chemical and structural characteristics compared to temperate grasses or legumes as potential compensatory forages. Especially monocotyledonous grasses show fundamentally different attributes than browse, whereas characteristics of legumes are largely convergent (Table 1).

**Table 1.** Chemical and structural characteristics of temperate grasses, forage legumes and browse[1]

| | Temperate C3-grasses | Forage legumes | Browse |
|---|---|---|---|
| *Chemical character* | | | |
| Cell wall material | Higher cell wall concentration with greater portion of cellulose and hemicelluloses | Lower cell wall concentration with greater portion of pectins and lignin | Lower cell wall concentration with greater portion of pectins, lignin and cutin-suberin |
| Plant defense compounds | Silicate | Phenolics (tannins) | Phenolics (tannins), terpenes, alkaloids and other toxins |
| *Structural character* | | | |
| Plant architecture | Lamina (blade) and sheath with parallel venation on full length, straight-sided epidermal cells | Lamina (leaflets) and petiole (leaf stalk) with reticulate venation, shorter initial length of veins, weakly lobed epidermal cells | Lamina (leaflets) and petiole (leaf stalk) with reticulate venation in a contiguous field, shorter initial length of veins |
| Terminal position of growth, growing height, habit | Near ground level, ground-proximate, homogenous | At end of elongated stem, ground-proximate | At tips, ground-proximate to high, very heterogeneous |

[1]According to Lagowski et al., 1958; Waite and Gorrod, 1959; Bailey, 1964; Van Soest and Jones, 1968; Bailey and Ulyatt, 1970; Hickey, 1973; Jarman, 1974; Robbins and Moen, 1975; Nastis and Malechek, 1981; Lees, 1984; Moseley and Jones, 1984; McLeod and Minson, 1985; Spalinger et al., 1986; Robbins et al., 1987; Nelsen and Moser, 1994; Van Soest, 1994; Tolera et al., 1997

According to the chemical and structural characteristics of the preferred plant material, the feeding types developed adaptations enabling the most effective comminution and digestion (Table 2). In line with the nomenclature ‘grazer’ and ‘browser’ in terms of preferences, the descriptions ‘cattle-type’ and ‘moose-type’ were based on adaptations of digestive physiology (Clauss et al., 2010). Whereas adaptations in cattle-types allow grazers to add a comparably wide range of forage to their rations without serious consequences, moose-types show a greater specification on browse and less ability for treatment of other forage (Van Wieren, 1996; Clauss et al., 2010). Due to the reduced scope of adaptability, browser nutrition is specifically demanding, certain nutrition-related disorders and phenomena occur and, unfortunately, browsers show a higher mortality in captivity than grazing ruminants (Müller et al., 2011).

**Table 2.** Adaptations in grazing and browsing ruminants due to characteristics of the preferred plant material[1]

| Plant characteristics | | | Adaptations in feeding type | | |
|---|---|---|---|---|---|
| | *Grasses* | *Browse* | | *Grazer/ Cattle-type* | *Browser/ Moose-type* |
| Qualitative uniformity of habit | + | – | Snout shape | Wide; short side opening | Slim; long side opening |
| | | | Tongue | Long torus | Long with mobile tip |
| Shape of particles | Long and bulky | Small and polygonal | Stratification of ingesta in rumen | + | – |
| Cell wall concentration | + | – | Retention time of particle phase; stratification of ingesta in rumen | + | – |
| Main cell wall constituents | Cellulose; hemicellulose | Lignin; pectins | | | |
| Plant defense | Silicates | Tannins | Size of salivary glands | – | + |
| | | | Saliva proteins | Silicate-specific | Tannin-specific |
| | | | Height of molar crowns | + | – |

[1]According to Schmuck, 1986; Austin et al., 1989; Hofmann, 1989; Robbins, 1993; Robbins et al., 1995; Clauss and Lechner-Doll, 2001; Archer and Sanson, 2002; Hummel et al., 2006a; Clauss et al., 2009; Codron and Clauss, 2010; Lechner et al., 2010; Clauss et al., 2011; Hummel et al., 2011; Mau et al., 2013; Tennant and MacLeod, 2014

Besides the limitation of alternate feed sources due to adaptations, a distinct preference for browse (Hatt et al., 2005) additionally limits the repertory of feeds for captive giraffes. Giraffes are known for their poor quantitative intake of grass hay (Foose, 1982), whereas lucerne hay of similar quality enables a higher forage intake in ruminants in general (Thornton and Minson, 1973). Regarding good acceptance and high resemblance to browse and thus to adaptations of moose-type ruminants, lucerne hay is recommended as compensatory forage for browsers (Hummel and Clauss, 2006). Nevertheless, it was shown that giraffes are unlikely to meet requirements exclusively on lucerne hay (Hatt et al., 2005). Therefore, recommendations on respective non-forage feeds are available, with dehydrated lucerne pellets, compound feeds and sugar beet pulp being suggested as most suitable options (Hummel and Clauss, 2006).

Even though recommendations have been given, rations for captive giraffe have been characterised by a considerable variety regarding amounts and choice of feedstuffs (Hummel et al., 2006b; Sullivan et al., 2010). Furthermore, the influence of uncertainties and the relevance of tradition in the nutrition of zoo animals are not to be underestimated, even though comprehensive research was done in terms of feeding captive browsing ruminants. Certain incompatibility of rations or ration components arises due to lack of dietary structural fibre as well as due to the limited suitability of compensatory fibre sources (Figure 1).

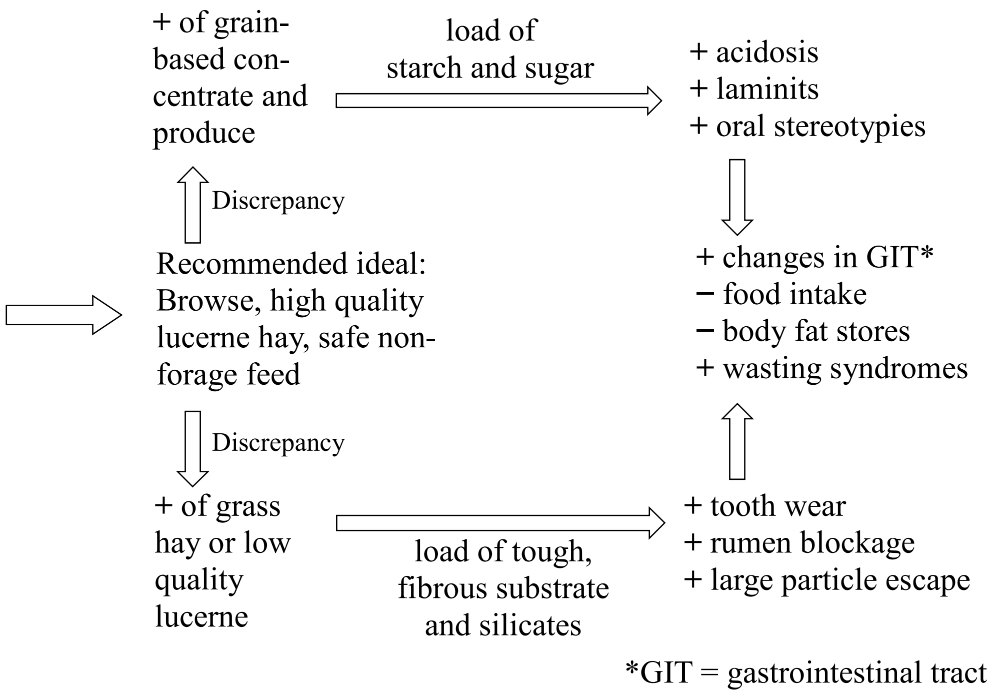


**Figure 1.** Relations between nutrition and consequences in browsing ruminants (modified from Hummel and Clauss, 2006)

With regard to the complex connection between characteristics of natural and alternate feeds, various capacities of browsing and grazing ruminants to handle them and the extent of inconsistency in practical feeding, further research on the nutrition of captive giraffes is indicated. As most prior studies were conducted under controlled conditions, but with limited numbers of animals or in single facilities, it was highly desirable to collect comprehensive data from practical feeding in numerous facilities to evaluate status quo and potential need for improvement directly on-site.

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# CHAPTER 2

## Scope of the thesis

This is a cumulative thesis composed of three manuscripts addressing the challenges and problems in giraffe nutrition in zoos as mentioned in the general introduction. The chapters 3 to 5 as main parts of the thesis compile the manuscripts that were formatted according to the regulations of the journal chosen for submission.

The implementation of a species-appropriate feeding practice for giraffes was expected to be possible if established feeding recommendations were applied. However, it was hypothesised that available recommendations on giraffe nutrition are not consequently applied and feeding practice among zoos shows considerable variation. By conducting a survey among the member zoos of the European Endangered Species Program (EEP) of the giraffe, potential variance was interrogated and the status quo in practical giraffe feeding was presented in Chapter 3. As the last collection of information on giraffe feeding happened a decade ago, there was need to renew the data base. The results were compared for concordance to feeding recommendations and examined on regional effects, thus if the local distribution of zoos was connected with aspects of feeding quality.

Secondly it was hypothesised that suboptimal feeding practices, being manifested in deviation from feeding recommendations, lead to typical phenomena and health restrictions in captive giraffes. Giraffe facilities in twelve German zoos were visited for documentation periods during which detailed information on ration characteristics were gained. Furthermore, data on animal variables were generated, which potentially indicate certain feeding faults. Results on the chemical analysis of provided feedstuffs were evaluated in Chapter 4. A detailed view was taken on the quality of and similarities between lucerne hay as recommended compensatory and temperate browse as most natural forage. Besides, provided non-forage feeds were evaluated with regard to their fermentative behaviour in terms of high-energy load. The linkage of ration characteristics to animal variables was picked up in Chapter 5 and was supposed to give integral insight into consequences of practical giraffe feeding. Potential relations of ration composition to the variable 'feed intake' were particularly investigated, as they were supposed to contain high reference to value the adequacy of rations. Furthermore, a conceivable influence of the ingested amount of forage on the pattern of behaviour was expected to illuminate the importance of sufficient structural fibre intake in ruminants.

The aim of this study was to evaluate the current situation in feeding practice for captive giraffe in Europe and to take advantage of variation in practical feeding among zoos to reveal the potential impact of different rations on animal physiology and behaviour. Data on rations and nutrition-related indicators in giraffes as generated in twelve German facilities were expected to be representative for the feeding situation in Europe as interrogated. With this approach an assessment of positive developments, well-established practice and room for improvement ought to be possible on a large number of zoos. Based on their quality and validity, the information shall improve knowledge, understanding and ultimately the practice of feeding giraffes and browsing ruminants in zoos in general.

## CHAPTER 3

# Feeding practice for captive giraffes (*Giraffa camelopardalis*) in Europe: A survey in EEP zoos

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## ABSTRACT

As with other browsing ruminants, the nutrition of giraffes (*Giraffa camelopardalis*) can be challenging. Feeding browse in very large amounts is not feasible. Therefore, substitutes need to be provided that have to meet requirements and the species' digestive capacity to the greatest possible extent. To achieve a comprehensive overview of current giraffe feeding practice in Europe, a survey was conducted among 153 member zoos of the European Endangered Species Program. Information from 81 returned questionnaires showed a considerable variety of feeds being provided in varying proportions. The use of lucerne hay (89% of the zoos) and fresh browse as trees or branches (96% of the zoos) was more common than stated in previous studies. The use of a pelleted compound feed was almost standard practice, but many rations additionally contained cereal grains as concentrates high in rapidly fermentable starch. Eighty-five percent of the zoos reported feeding fresh fruits and vegetables, even though this is not recommended due to high contents of sugar with potentially negative influence on ruminal fermentation. The estimated non-forage proportion (sum of concentrate feeds, fruits and vegetables) in the overall dietary dry matter (DM) was 37% in summer and 43% in winter (median), which is in accord with recommendations. However, a considerable range of non-forage proportions was determined, with 43% of the zoos providing amounts that were likely exceeding 50% of the potential daily DM intake. Data on dietary proportions revealed a geographical distribution, with zoos from *Western Europe* showing the lowest and zoos from *Eastern European* showing the highest proportions of concentrate feeds in the rations. An index of feeding appropriateness, oriented towards conformity with feeding recommendations, may be useful to evaluate and improve feeding management precisely and individually, as room for improvement was revealed for half of the participating zoos.


**Key words**: browse, concentrate, dietary proportion, dry matter intake, forage, produce

## INTRODUCTION

The European Endangered Species Program (EEP) of the giraffe (*Giraffa camelopardalis*) unites 153 giraffe facilities and increasing numbers of animals were registered during the last decade (Jebram 2012). Nevertheless, giraffe husbandry poses challenges and the European Association of Zoos and Aquaria (EAZA) has published husbandry and management guidelines (EAZA Giraffe EEPs 2006). The feeding of giraffes is a matter of particular interest in these recommendations, since multiple husbandry problems in giraffes are reported to be nutrition related (e.g. Bashaw et al. 2001; Clauss et al. 2006; Hummel et al. 2006a). Giraffes are classified as browsing ruminants (Van Soest 1988; Hofmann 1989), which are generally considered to be more challenging to feed in captivity compared to grazing ruminants in general (Clauss et al. 2003; Clauss and Dierenfeld 2007). On the one hand, being a ruminant implies a forage fibre requirement to maintain an efficient rumen function (Van Soest 1994). On the other hand, forages or fibrous feeds should match the digestive physiological adaptations of browsers against the background of chemical and structural particularities of browse compared to temperate grasses (Bailey 1964; Bailey and Ulyatt 1970; Robbins and Moen 1975; Demment and Van Soest 1985; Spalinger et al. 1986). Year-round feeding of browse in large amounts is logistically demanding in temperate zones with a period of dormant vegetation. Appropriate substitutes need to be combined in proper ratios to meet nutrient and energy requirements and to prevent pathological consequences or behavioural disturbances. The main focus in feeding instructions is on providing rations with sufficient amounts of palatable high quality forage (at least 50% of ration dry matter (DM); Schmidt and Barbiers 2005; Hummel and Clauss 2006). In several aspects, lucerne shows chemical and structural characteristics similar to browse (Hummel et al. 2006b; Hummel et al. 2006c), enables a comparably high forage intake in ruminants in general (Thornton and Minson 1973; Waghorn et al. 1989) and is much better accepted by giraffes than grasses (Foose 1982). In addition, browse should be supplied for nutrient supplementation and behavioural enrichment (Valdes and Schlegel 2012). As additional fibre source, dehydrated lucerne pellets are recommended (Hummel and Clauss 2006). Energy-rich ration ingredients should be based on suitable compound feeds or components rich in easily digestible cell wall constituents like unmolassed sugar beet pulp. The use of cereal grain products and commercial fruits and vegetables should be restricted to minimum (Hummel and Clauss 2006). Due to high contents of starch and sugar (Schmidt et al., 2005), any over-use of such feeds increases the risk of nutrition-related disorders (Potter and Clauss 2005; Clauss et al. 2006; Hummel et al. 2006a).

Along with current reports on feeding practice in other browsing ruminants (Wright et al. 2011; Taylor et al. 2013), the last overview of giraffe nutrition was reported by Hummel et al. (2006d) for European zoos and by Sullivan et al. (2010) for North American institutions. Some potential for further improvement of giraffe feeding became apparent. The use of lucerne hay was confirmed to be common by Hummel et al. (2006d), but also the use of non-forage feeds in amounts corresponding to an average proportion of 51% of DM intake was found. Sullivan et al. (2010) determined considerable variation in the offered forage to concentrate-ratio (FC ratio; range of 18 to 77% concentrate feed in the ration as fed) and only 65% of the facilities reported feeding browse. Almost one decade later the present nutritional survey was conducted (1) to gain a comprehensive level of knowledge on current giraffe feeding practice in European facilities and (2) to evaluate developments and trends in giraffe nutrition. Additionally, (3) the geographical location of zoos and structure of herds in the zoos were considered to evaluate geographic or group-specific effects on feeding practice among EEP zoos.

## MATERIAL AND METHODS

### Questionnaire

The survey was conducted using a questionnaire (Appendix AI) that was sent to the zoos (n = 153) of the giraffe EEP. The questionnaire was structured in four sections: (1) general information on number, date of birth, sex and subspecies of animals in a facility, (2) information on forage feeding, (3) information on feeding of non-forage feeds (concentrates: compound feeds, dehydrated lucerne pellets, straight feeding stuffs (cereal grain products, sugar beet pulp); produce: fruits, vegetables) and (4) additional information on general feeding practice. Questions in sections two and three needed to be answered separately for summer and winter season. Zoos could give information on amounts of feed either referring to one individual or to the whole group of giraffes. Amounts were generally given as fed. In case of further enquiries, the respective contact person was asked. For evaluating regional effects, participating zoos were sorted geographically to *Western Europe*, *Northern Europe*, *Eastern Europe* and *Southern Europe including Middle East.*

**Dry matter intake and forage to concentrate-ratio**

Offered amounts of feed were standardised from volumes to weights if necessary (Madgwick and Satoo 1975; BVL 2002; Hatt and Clauss 2006; Spiekers et al. 2009; Mosig 2012) and converted into DM, using standard data collections on animal feeds (Universität Hohenheim – Dokumentationsstelle 1997; DLG 2010; Agroscope 2013). Body weights (BW) were estimated using the data collection of BW development in giraffes by Reason and Laird (2004). Theoretical DM intake (DMI) related to metabolic body size (kg $BW^{0.75}$) was estimated using own data collections on DMI in giraffes (Table 3), which were prepared from DMI documentation in twelve German zoos based on metabolisable energy (ME) requirement and consideration of the individual status of performance (lactation, growth) of each animal. The data base was within the range of values published on DMI in giraffes (Prins and Domhof 1984; Baer et al. 1985; Hatt et al. 1998; Dinglreiter 2000; Clauss et al. 2001). If not declared otherwise, offered amounts of concentrate and produce were supposed to be completely consumed (as e.g. done so by Hummel et al. 2006d), resulting in the term estimated non-forage proportion which was taken to calculate the potential FC ratio.

The classification of dehydrated lucerne pellets and pelleted browse-based product as non-forage feeds was done with reference to the different physical structure and irrespective of its potential similarities in nutrient composition with lucerne hay or dried browse.

**Table 3.** Database for estimation of dry matter intake (DMI) and forage to concentrate ratio in groups of giraffes, based on data on DMI (g/kg $BW^{0.75}$/d) calculated for 97 giraffes in twelve German zoos in consideration of energy requirement depending on status of lactation or growth.

| Age | Status | Male | Female | Juvenile |
|---|---|---|---|---|
| | | g DMI/kg $BW^{0.75}$/d | | |
| > 2.5 years | Maintenance | 62 | 59 | - |
| | Lactation month 1-6 p.p. | - | 121 | - |
| | Lactation month 7-9 p.p. | - | 94 | - |
| | Lactation month 9-12 p.p. | - | 81 | - |
| 2.5-1.75 years | Growth | - | - | 75 |
| 1.75-1.25 years | Growth | - | - | 83 |
| 1.00-1.25 years | Growth | - | - | 71 |
| 9-12 months | Growth | - | - | 64 |
| 7-9 months | Growth | - | - | 46 |
| 4-6 months | Growth | - | - | 26 |
| < 4 months | n.c. | - | - | n.c. |

kg $BW^{0.75}$ = metabolic body size; p.p. = post partum; n.c. = not considered

**Index of feeding appropriateness**

A scoring system was developed (Table 4) to assign an index of feeding appropriateness (IFA) to every zoo according to conformity with feeding recommendations by using the equation

$$\text{IFA} = (2 \cdot a) + (2 \cdot b) + c + \sum d + \sum ((\% \text{ of respective concentrate feed in the concentrate portion in DM}/100) \cdot e) + \sum f.$$

**Table 4.** Index variables and scoring system for calculating the index of feeding appropriateness (IFA)[1]

| Variable | -2 points | -1 point | 1 point | 2 points |
|---|---|---|---|---|
| Percentage of non-forage feeds (a) and produce (b) in ration DM | > 70%<br>> 5% | 50-70%<br>2-5% | 30-50%<br>0.1-2% | < 30%<br>0% |
| Feeding of non-forage feeds per day (c) | | 1 time | ≥ 2 times | |
| Types of main forage in the ration (d) | | − Grass hay | − Lucerne hay *and/or*<br>− Browse[2] seasonal | − Browse[2] year-round |
| Composition of the concentrate portion (% of concentrate feed in the concentrate portion in DM) (e) | | − % of cereal grains/100 | | % of<br>− Compound feed *and/or*<br>− Dehydrated lucerne pellets *and/or*<br>− Beet pulp<br>/100 |
| Feeding of additional forage (f) | | | − Fresh forage[3] *and/or*<br>− Browse ensiled/ frozen/dried | |

[1]IFA = $(2 \cdot a) + (2 \cdot b) + c + \sum d + \sum((\%$ of respective concentrate feed in the concentrate portion in DM/100$) \cdot e) + \sum f$, each bullet point in section d, e and f counts individually; [2]Whole trees and branches; [3]Fresh lucerne, nettles, blackberry, thistles, rose leaves

Scores included in the index calculation encoded respective non-forage proportions (a; minimum (min.) -4, maximum (max.) 4 points), produce proportions (b; min. −4, max. 4 points), feeding frequency of non-forage feeds per day (c; min. −1, max. 1 point), types of main forage in the ration (d; min. −1, max. 3 points), composition of the concentrate portion (e; min. −2, max. 2 points) and feeding of additional forage (f; min. 0, max. 2 points). Due to the high relevance of FC ratio in ruminant nutrition, variables a and b were multiplied by two in the index equation. Section e refers to the proportion of a respective concentrate feed in the whole portion of concentrates in DM. Each bullet point in sections d, e, and f is counted individually. An increasing IFA represented increasing feeding appropriateness (evaluation scale from −12 to 16 points). To evaluate the results, the scale was quartered (results ≤ 0 points, 1 to 6 points, 7 to 11 points and ≥ 12 points) and the mean index value was taken as critical value.

### Statistical evaluation

Due to extreme outliers, proportions of FC ratio were averaged by median and first and third quartiles are given to show variances. Other values are presented as arithmetic mean with standard deviation (SD). Seasonal differences on forage and non-forage proportion were tested with the Tukey test. To evaluate geographical or group-specific effects (number and age of animals), an analysis of variance was conducted with region, number of animals and mean age of animals per group as fixed effects and comparison of least squares means of the variables forage proportion and produce proportion using the Tukey test. Subsequently, a cluster analysis was conducted for the variables forage proportion and produce proportion (hierarchical method of Ward, 3 cluster-algorithm) and the geographical distribution of zoos and distribution of group-specific characteristics among the clusters was enumerated. Differences between the clusters were tested with a Student's t-test. All statistical tests were done using software program SAS 9.3 (SAS Institute Inc, Cary, North Carolina, USA) and results were considered significant at $p \leq 0.05$.

## RESULTS

### Zoo and group information

A response rate of 53% was achieved representing 81 separately managed groups of giraffes from 22 countries. The participating zoos were located in Austria (1), Belgium (2), Czech Republic (4), Denmark (5), France (10), Germany (16), Hungary (2), Ireland (2), Israel (2), Italy (2), Lithuania (1), the Netherlands (8), Poland (3), Portugal (1), Serbia (1), Slovakia (1) Slovenia (1), Spain (3), Sweden (2), Switzerland (1), the United Arab Emirates (1) and

United Kingdom (12). The geographical distribution of the responding zoos was representative for the geographical distribution of the contacted EEP member zoos with 65% respondents from *Western Europe*, 9% from *Northern Europe*, 16% from *Eastern Europe* and 10% from *Southern Europe including Middle East.* By mean (± SD) the groups of giraffes consisted of six (± 3; range of 1 to 18) giraffes which were eight (± 2.7; range of 3.8 to 14.3) years old.

**Ration composition**

Lucerne hay was fed in 89% of the facilities, with 96% of those using it year-round and 4% during winter time only. Grass hay was fed in 27% of the facilities (seasonally only in 18% of those) and grass-clover hay was used in 2% of the zoos. During summer, fresh lucerne and fresh grass was provided in 17% and 30% of the facilities, respectively. One facility provided fresh lucerne and grass year-long. In 2% of the facilities molassed lucerne hay was fed; grass haylage, lucerne silage, chopped lucerne hay or grass silage was used in single zoos only. Ninety-six percent of the facilities stated to feed fresh browse, 86% of those during summer (as leafy twigs and trees) and winter (as twigs and trees without leaves). Frozen browse (9%), browse silage (7%) and dried browse (31%) were used as forage sources during winter; the latter was also fed year-round in four and during summer in one facility. Thirty-one different types of browse were supplied in the zoos. Willow was most commonly used (81% of the facilities) followed by birch (51%), beech (44%), oak (44%), ash (41%), hazelnut (39%), robinia (35%), maple (22%), various types of berries (18%), fruit trees (15%) and hawthorn (13%). Additionally, nettles (6% of the facilities), blackberry, thistles and rose leaves (single facilities only) were provided as fresh summer forage. Seven percent of the zoos provided whole maize plants or maize stover during the growing season. Forages were fed in various combinations (Table 5), with the combination of preserved lucerne supplemented with browse, or preserved lucerne supplemented with fresh forage and browse being the most common combinations. Lucerne-free forage portions were fed in 8 % of the zoos with either grass hay/haylage or grass-clover hay being the main forage source. Two facilities did not provide any browse.

**Table 5.** Combinations of forage fed in the percentage of respondent zoos.

| Lucerne hay/ chopped/ ensiled/ molassed | Grass hay/ haylage/ silage | Grass-clover hay | Fresh forage (lucerne, grass, nettles, blackberry, thistle, rose leaves) | Browse fresh/ frozen/ dried/ ensiled | Fed in % of the zoos |
|---|---|---|---|---|---|
| • | | | | • | 40 |
| • | | | • | • | 26 |
| • | • | | • | • | 19 |
| | • | | • | • | 5 |
| • | • | | | • | 4 |
| | • | | | • | 2 |
| • | | | | | 1 |
| • | • | | • | | 1 |
| | | • | | • | 1 |
| • | | • | • | • | 1 |

All responding zoos fed some concentrate. With 96% almost all facilities stated to use compound feed; 50% of the products were declared as specific for browsers or giraffes. Dehydrated lucerne pellets were provided in 30% and a pelleted browse-based product in 11% of the facilities. In 19% of the facilities sugar beet pulp was used. Energy-rich cereal grain products (wheat flakes, oat flakes, barley flour, corn meal, broken corn, whole corn) and fibre-rich cereal grain products (crushed oats, wheat bran, oat bran) were part of the ration in 33% of the zoos, with 26% of those feeding energy-rich, 37% combining energy- and fibre-rich and another 37% feeding only fibre-rich cereal grains. Nine percent of the respondents fed soya-bean meal (solvent-extracted) and 16% fed linseed as supplement. Additionally, "giraffe cereals" and a "pasture mix" were used, each in one case. Regarding combinations of concentrate feeds (Table 6), the exclusive use of compound feed was most common (26% of the zoos). The next most frequent combinations were feeding of compound feed with cereal grains (14%), with dehydrated lucerne pellets (12%), with a pelleted browse-based product (7%) or with sugar beet pulp (7%). The remaining 30% of the zoos provided further combinations resulting in mixtures of up to five ingredients. Forty percent of the zoos provided concentrates one time per day, 52% at two times, 7% at three times and one facility stated to feed concentrate feeds at five times per day

**Table 6.** Combinations of concentrate feeds fed in the percentage of respondent zoos.

| Compound feed | Cereal grain products | Protein supplement | Dehydr. lucerne pellets | Browse-based product | Beet pulp | Linseed | Fed in % of the zoos |
|---|---|---|---|---|---|---|---|
| • | | | | | | | 26 |
| • | • | | | | | | 14 |
| • | | | • | | | | 12 |
| • | | | | • | | | 7 |
| • | | | | | • | | 7 |
| • | • | | | | • | | 4 |
| • | • | | • | | | | 4 |
| • | • | • | • | | | • | 4 |
| • | | | | | | • | 4 |
| • | • | | • | | | • | 2 |
| • | • | | | | | • | 2 |
| Combinations fed in single facilities | | | | | | | 14 |

Of all participating zoos, 85% made use of produce in their giraffe ration. Fifty-three percent of those provided both fruits and vegetables, 46% vegetables only and 1% fruits only. Except five facilities, all stated to feed produce year-round. In the produce feeding zoos, apples (59%) and bananas (26%) were most commonly fed followed by citrus fruits (9%) and others (7%). Regarding vegetables following types were used: carrots (77%), cabbage and celery (30% each), onions and beetroot (29% each), salads (26%), kohlrabi (19%), herbs (10%), radish, leek and potatoes (9% each), fennel and chard (6% each), celeriac, chicory and peppers (4% each), tomatoes, cucumber, maize cob, scallions, endive and zucchini (3% each) and pumpkin, spinach, aubergine, fodder beet, garlic, cole and turnips (each in single facilities). Produce was fed one time per day in 43% and two times per day in 49% of the zoos. Three zoos stated to feed fruits and vegetables at three times per day, another three zoos provided it during training sessions.

### Dry matter intake and forage to concentrate-ratio

Thirty-eight percent of the respondents gave separate information for feeding of concentrates and produce in summer and winter season, respectively, but there was no statistically evident seasonal difference. During summer season, a median content (1$^{st}$ quartile/3$^{rd}$ quartile) of 35% (23/50) of concentrates and 2.2% (0.5/4.2) of produce in ration DM was estimated. The median estimated forage content was 62% (48/72). During winter season, an amount of 41% (28/57) of concentrates and 2.2% (0.6/4.5) of produce in ration DM was estimated and the median content of forage was 54% (41/69). A reasonable estimation of DMI and FC ratio was not possible for six zoos due to feeding of non-forage feeds for *ad libitum* intake or a satisfaction of theoretical DMI by high offers of concentrates and/or produce. Detailed information on estimated DMI and FC ratio is given in Table 7.

**Table 7.** Proportion of forage, concentrate and produce in rations (% of dry matter (DM)) based on reported amounts of non-forage feeds and estimated proportion of forage derived from potential daily dry matter intake during summer and winter season.

| | Winter | | | Summer | | |
|---|---|---|---|---|---|---|
| | Forage | Concentrate | Produce | Forage | Concentrate | Produce |
| Median | 54 | 41 | 2.2 | 62 | 35 | 2.2 |
| $1^{st}$ Quartile | 41 | 28 | 0.6 | 48 | 23 | 0.5 |
| $3^{rd}$ Quartile | 69 | 57 | 4.5 | 72 | 50 | 4.2 |
| Mean | 53 | 44 | 2.9 | 58 | 39 | 2.8 |
| SD | 22 | 21 | 2.8 | 20 | 20 | 2.8 |
| Minimum | 2.2 | 10 | 0.0 | 2.2 | 2.9 | 0.0 |
| Maximum | 89 | 91 | 13 | 93 | 90 | 13 |

**Influence on dietary proportion**

During analysis of variance, the location of zoos had a significant effect on the dietary forage ($p = 0.003$), concentrate ($p = 0.007$) and produce proportion ($p = 0.020$), with rations from *Western Europe* containing more forage ($p = 0.009$) and less concentrate ($p = 0.028$) than rations from *Eastern European* zoos. The number or age of animals in a group had no effect on the dietary proportion. The cluster analysis revealed clusters according to low, medium or high dietary proportion of forage ($p < 0.001$) or concentrate ($p < 0.001$), but produce proportion did not differ between the clusters. The number of animals and age of animals were likewise not different between the clusters (Table 8). The distribution of zoos among the clusters was allocatable due to their geographical location (Table 9). Particular differences between *Western* and *Eastern European* zoos became visible, with 54% of *Western European* zoos and 15% of *Eastern European* being summarised in cluster 3 (high forage proportion).

**Table 8.** Proportion of forage, concentrate and produce in rations, number of animals and age of animals in the clusters (mean ± SD; minimum/maximum); significant differences ($p \leq 0.05$) between clusters are labeled with different letters in the same line

| | Cluster 1 (n = 11) | Cluster 2 (n = 32) | Cluster 3 (n = 33) |
|---|---|---|---|
| Forage (% of ration DM) | $21^a \pm 11$ | $59^b \pm 8.1$ | $74^c \pm 7.9$ |
| | 2.2/46 | 33/62 | 62/89 |
| Concentrate (% of ration DM) | $75^a \pm 12$ | $48^b \pm 7.7$ | $23^c \pm 8.0$ |
| | 46/90 | 36/62 | 7.8/34 |
| Produce (% of ration DM) | 3.8 ± 2.9 | 2.5 ± 2.7 | 2.8 ± 2.8 |
| | 0.4/7.9 | 0/10 | 0/13 |
| Animals (number) | 5.3 ± 2.7 | 5.9 ± 2.9 | 5.5 ± 3.6 |
| | 1/10 | 2/15 | 2/18 |
| Age (years) | 8.8 ± 3.2 | 8.5 ± 2.7 | 7.3 ± 2.4 |
| | 4.4/13.9 | 3.8/14.3 | 3.9/14.3 |

**Table 9.** Distribution of zoos in the clusters according to geographical location (cluster 1 = low forage proportion; cluster 2 = medium forage proportion; cluster 3 = high forage proportion)

| | Cluster 1 (n = 11) | Cluster 2 (n = 32) | Cluster 3 (n = 33) |
|---|---|---|---|
| % of Western European zoos | 8 | 38 | 54 |
| % of Northern European zoos | 25 | 75 | 0 |
| % of Eastern European zoos | 39 | 46 | 15 |
| % of Southern European zoos incl. Middle East | 12 | 44 | 44 |

**Index of feeding appropriateness**

A mean index value (± SD) of 6 points (± 5) was observed with a minimum score of −4 and a maximum score of 14 points. In a quartered scale, 13 facilities achieved a value ≤ 0, 31 facilities achieved 1 to 6 points, 31 facilities achieved 7 to 11 points and six facilities reached ≥ 12 points. Taking the overall mean as critical value, 54% of the zoos were in the lower and 46% in the upper half of the scale. IFA results > 6 points were achieved by 59% of the *Western European* zoos, 38% of the *Northern European* zoos, 23% of the *Eastern European* zoos and 11% of the zoos from *Southern Europe including Middle East* (Table 10).

**Table 10.** Distribution of zoos (%) in scoring ranges during evaluation of feeding practice using an index of feeding appropriateness (IFA) (increasing value = increasing feeding appropriateness; evaluation scale = −12 to 16 points).

| IFA scoring range | All regions | Western Europe | Northern Europe | Eastern Europe | Southern Europe incl. Middle East |
|---|---|---|---|---|---|
| ≤ 0 points | 16 | 10 | 12 | 46 | 11 |
| 1 to 6 points | 38 | 31 | 50 | 31 | 78 |
| 7 to 11 points | 38 | 47 | 38 | 23 | 11 |
| ≥ 12 points | 8 | 12 | 0 | 0 | 0 |

## DISCUSSION

The results of the present survey showed that feeding of giraffes in Europe is in fact characterised by considerable variety, as previously determined for other captive browsing ruminants (Clauss et al. 2002; Wright et al. 2011; Taylor et al. 2013). An established use of preserved lucerne, for the most part as lucerne hay, exceeds the number of zoos feeding lucerne hay in the report by Hummel et al. (2006d) (Table 11). In contrast, the use of grass hay decreased; less zoos made use of grass hay but more fed recommended lucerne hay. Besides, some zoos fed grass-clover hay that might likewise be more suitable for giraffes than pure grass hay due to similar patterns in fibre fractions compared to lucerne or browse species (Jayanegara et al. 2011). During summer, 52% of the zoos in our study used fresh forage which is comparable to the percentage of zoos feeding fresh forage in the survey of Hummel et al. (2006d). Fresh forage did not undergo any conservation process, thus nutrient characteristics and energy content are higher compared to the preserved product. However, in the former study exclusively fresh grass was used, while currently 19% of the zoos stated to feed fresh lucerne. Just as the dried counterpart, fresh lucerne is regarded as more appropriate for giraffes than pure grasses (Hummel and Clauss 2006). Furthermore, fresh nettles, thistles, blackberry and rose leaves were used in at least 12% of the facilities. These unconventional fodder plants can also present good quality complementary forage for giraffes due to similar chemical characteristics compared to lucerne and high nutritive values (Hummel et al. 2009; Nijboer pers. com.).

**Table 11.** Feeding of forage as reported by Hummel et al. (2006d) compared to information from the present survey

| | Hummel et al. (2006d) | Present data |
|---|---|---|
| Grass/lucerne | | |
| Lucerne hay | 81% | 89% |
| Grass hay | 40% | 27% |
| Ensiled lucerne/grasses | - | 4% |
| Browse | | |
| Fresh browse (trees and branches) | 80% | 96% |
| Dried/ensiled/frozen browse | 4% | 47% |
| Fresh forage | | |
| Grass | 53% | 31% |
| Lucerne | - | 19% |
| Nettles, thistles, blackberry, rose leaves | - | 12% |

The number of zoos that provided some browse with the ration, especially during winter season, increased compared to the survey of Hummel et al. (2006d) (84%) and the study of Sullivan et al. (2010) (65%). Fresh branches and/or trees were commonly used in 96% of the present zoos, and dried or ensiled browse was also fed in several facilities. Three facilities stated to feed fresh browse since the giraffes were able to browse from natural vegetation around the enclosure. Individual cases may differ, but vegetation in or around giraffes' enclosures is typically cropped in short time and does not appear sufficient to assume a quantitatively relevant intake of browse. While this may still be advantageous for activity budgets, foraging would be reduced to extensive searching for browse over fences instead of actual feed intake. To prevent oral stereotypies (Koene and Visser 1999; Bashaw et al. 2001; Hummel et al. 2006a) and maximise intake activity, an additional supply of browse should be considered essential in the nutrition of browsing ruminants, irrespective of the natural browse availability around an enclosure.

Feeding concentrates is an efficient and easy way to supply energy and nutrients of constant quality (Sullivan et al. 2010). To improve feeding of concentrates, composition and supplied amounts need to be considered. Fortunately, the use of compound feeds became more common in European zoos during the last years. It can be assumed that these products are mostly suitable to meet the animals' demands with a higher suitability and safety regarding rumen physiology as compared to pure cereal grain products. Starch as rapidly fermentable carbohydrate is characterised by a high acidogenicity value indicating the potential to trigger unphysiological conditions in the rumen (Menke and Steingass 1988; Van Soest et al. 1991; Odongo et al. 2006). Therefore, the use of fibre-rich non-forage feeds like unmolassed sugar beet pulp or dehydrated lucerne pellets is recommended (Hummel and Clauss 2006). Especially unmolassed sugar beet pulp has been reviewed as a suitable energy source for browsers (Hummel et al. 2003; Kearney, 2005). Instead of starch, it contains pectins as easily fermentable component of the cell wall which shows a higher cation exchange capacity and a more even gas production during fermentation (Van Soest et al. 1991; Jeroch et al. 1993; Hummel et al., 2006b). Nevertheless, only 16 facilities made use of it.

Whether or to which extent the feeding of produce is really required for large herbivores has been discussed repeatedly (Oftedal et al., 1996; Hummel et al. 2003; Clauss and Hatt 2006; Hummel and Clauss 2006). Due to high amounts of rapidly fermentable sugar, produce shows an immediate, 'explosive' fermentation which can potentially trigger acidotic conditions in the rumen (Van Soest 1987; Oftedal et al. 1996). This was recently shown to be the case in different zoo ruminant species being fed with rations high in easily fermentable carbohydrates (Schilcher et al. 2013; Ritz et al. 2014). In the present survey, 85% of the participating facilities made use of produce as a more or less relevant ration component. Twenty-six percent exceeded the recommendation of at most 1% fruits in ration DM; 16% exceeded the recommendation of at most 4% vegetables in ration DM (Hummel and Clauss, 2006). Obviously the use of commercial fruits and vegetables is still common, even though from a purely nutritional point of view it should not be considered as a desirable or even necessary part of the ration. The main reason for feeding fruits and vegetables is probably the high palatability, which makes produce useful during training and medical treatments.

The distribution of concentrate portions over the day is important for conditions in the rumen. It must be noted that 35% of the zoos provided non-forage feeds in one large portion per day, which increases the probability of a considerable pH drop in the rumen (Hummel et al. 2006b). Feeding of non-forage feeds in smaller portions has beneficial effects on rumen pH (Kaufmann 1976) and the time span for food consumption can be elongated. Therefore, a provision of non-forage feeds in at least two portions and with maximum time lag between the feeding times is recommended (Hummel and Clauss 2006).

The present information showed an average non-forage proportion of 37% in summer rations and 43% in winter rations (median). Correspondingly, the median amount of forage was above the limit of 50% of ration DM and in line with the EAZA recommendations (Hummel and Clauss 2006). Therefore, the currently estimated FC ratio has improved in contrast to former results by Hummel et al. (2006d) or was in line with the results by Sullivan et al. (2010). At the same time a very large variance in potential FC ratio similar to the results of

Sullivan et al. (2010) was observed, showing that practical giraffe feeding is still of considerable heterogeneity. The estimated proportions of concentrate appeared as decisive variable for distance calculation in the cluster analysis, whereas no difference was found for the produce proportions. Obviously the use of fruits and vegetables is independent from other ration characteristics and evenly established among zoos, whereas the quantitative use of concentrate specifically varies among the zoos.

The calculation of the potential FC ratio was done assuming the complete intake of concentrates and produce as supplied. Therefore, an overestimation of the respective amount of non-forage proportion in certain rations was possible, if the amount of concentrate and/or produce was particularly high and potentially not completely consumed by the animals. This could lead to questionable results regarding extreme outliers (Table 7). Nevertheless, in the respective cases concentrates and/or produce were provided more or less for *ad libitum* intake, which is critical. Regulation of DMI in ruminants was described to happen due to energetic satiety in case of easily digestible rations with high energetic density (Conrad 1966; Waldo 1986; Jung and Allen 1995). Increasing dietary energy values due to high amounts of concentrates and produce may therefore adversely affect forage intake, resulting in the consumption of a low forage proportion.

The IFA shows that 54% of all participating EEP member zoos did not reach the upper half of the scale, and therefore potential for improvement in feeding management and lack of concordance with recommendations was given. On the other hand, approximately half of the zoos showed an adequately calculated proportion of non-forage feeds in the ration and an extended use of various forage sources. On a quartered scale, only six zoos from *Western Europe* achieved ≥ 12 index points. These zoos stood out for an adequate non-forage proportion, the choice of recommended concentrate feeds and an ambitious use of preserved browse and additional fresh forage in the ration.

Regarding the regional distribution of zoos in the clusters (Table 9) it was noticeable that zoos from *Eastern Europe* were mainly summarised in Cluster 1 (low forage proportion) and Cluster 2 (medium forage proportion) whereas zoos from *Western Europe* were mainly summarised in Cluster 2 and Cluster 3 (medium and high forage proportion). Apparently feeding of concentrate in high amounts was most common in *Eastern European* zoos. Supplementary feeding of high energy feeds could rather be assumed for *Northern European* facilities due to higher energy requirements for thermoregulation in the boreal area, which was not confirmed tough. Looking at the IFA results, thus feeding practice as a whole, more than half of the zoos from *Western Europe* and a comparatively high number of zoos from *Northern Europe* reached the upper half of the scale, indicating a high level of feeding appropriateness. Due to considerably high amounts of non-forage feeds, many zoos from *Eastern Europe* could not reach a value > 6 index points. Taking the IFA results, feeding practice in zoos from *Southern Europe including Middle East* appeared less positive than in the cluster analysis. Even though these zoos showed medium to high forage proportions, feeding practice lacked concordance to recommendations, as grass hay and/or cereal grains were part of the ration in 90% of the facilities. Furthermore, the use of additional fresh forage was practiced in only one zoo from *Southern Europe including Middle East*. The results of the cluster analysis and the index evaluation should be taken as clear indication for differences in feeding practice across Europe, with higher improvement potential being visible in zoos from *Eastern* and *Southern Europe including Middle East*, which raised the question of reasons for geographical differences in feeding practice. As a precondition for improvement, it would be highly desirable to further investigate if tradition, finances, management or even some climatic causes were of reason here. An IFA as developed in this study may then be a useful tool to identify striking and improvable factors in practical feeding management of giraffe facilities, as strength and weaknesses become more clearly visible by scoring individual factors orientated on feeding recommendations.

## CONCLUSIONS

The motivation of numerous zoos to participate in the survey with personal queries and suggestions mirrored the high interest in issues of giraffe feeding in European facilities. A large number of feedstuffs and combinations of feedstuffs were documented and proportions of feeds varied considerably. Preferable trends and desirable developments were clearly visible, but improvement opportunities were also obvious, as in former investigations.

- Lucerne hay provided for *ad libitum* intake was nearly standard in the participating facilities and a percentage higher as interrogated before supplied browse year-round. The use of fresh forage or preserved browse might be possible for more zoos, if unconventional fodder such as nettles or dried browse was used.
- As recommended, the estimated forage proportion represented more than 50% of ration DM. Nevertheless, the potential extent of non-forage feeds in the rations differed significantly, resulting in diverging calculated ration proportions. Concentrates should be

dosed and chosen with due care. The use of pelleted compound feeds, unmolassed sugar beet pulp and dehydrated lucerne pellets is recommended and at least the former was used extensively. The feeding of less cereal grain-based rations would be highly desirable.

- Even though fresh fruits and vegetables are not recommended as significant parts of giraffes' rations, more than three-quarters of the zoos stated to use them regularly. Input should be strictly limited to particular purposes like medical treatment.
- Effects of the geographical location of zoos were shown for the dietary proportions and the IFA results, with zoos from *Eastern* and *Southern Europe including Middle East* revealing higher potential for improvement than *Western European* zoos. The use and advancement of an index system to evaluate feeding appropriateness could help to identify weakness and strength in particular management aspects of single facilities.

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# CHAPTER 4

## Chemical composition and fermentation characteristics of feedstuffs for giraffes (*Giraffa camelopardalis*) in German zoos

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## ABSTRACT

The objective of the study was to evaluate feedstuffs from giraffe nutrition in zoos. A total of 196 samples in six categories of forage (n = 111) and eight categories of non-forage feeds (n = 85) was analysed for chemical composition and *in vitro*-gas production (GP). Lucerne hay as main forage source showed a stable average quality (mean ± standard deviation: crude protein = 179 g · $kg^{-1}$ dry matter (DM) ± 19; metabolisable energy = 8.9 MJ · $kg^{-1}$ DM ± 0.6) and concordance to browse leaves regarding content of fibre fractions. Depending on the type, browse showed large variation in composition and fermentation. Supplementation of polyethylene glycol as tannin-binding agent led to significantly increasing GP in leaves and bark. According to application, non-forage feeds differed in contents of energy, protein and fibre fractions. Regarding chemical composition and GP, dehydrated lucerne pellets were largely similar to lucerne hay and compound feeds were generally balanced. Sugar beet pulp offered the highest ability to ensure a beneficial, even fermentation compared to other high-energy feeds. A dietary substitution of produce with sugar beet pulp led to less distinct peaks in the theoretical additive GP over 24 hours. Present recommendations on feedstuffs were generally confirmed, but the protein delivering capacity of lucerne hay was suspected to be undervalued in captive giraffe nutrition. Comprehensive analyses of leaves and bark resulted in a valuable complement of information on temperate browse.


**Key words:** browse, metabolisable energy, forage, gas production, lucerne hay, sugar beet pulp

## INTRODUCTION

In accordance with their classification as purely browsing, but comparatively little selective ruminants (Van Soest, 1988; Hofmann, 1989; Steuer et al., 2014), giraffes (*Giraffa camelopardalis*) forage efficiently for *Acacia sp.* under natural conditions (Pellew, 1984). In a zoo environment foraging is much less complex (Baer et al., 1985). Browse access is limited due to seasonal restrictions or individual management and energy, physically effective fibre and nutrients must be supplied with alternative feedstuffs. In alternate forage the chemical and structural composition of the cell walls should resemble browse (Robbins and Moen, 1975; Tolera et al., 1997; Hummel et al., 2006a), which widely applies to lucerne hay (Lagowski et al., 1958; Bailey and Ulyatt, 1970). Furthermore, lucerne hay enables high forage intake in ruminants in general (Thornton and Minson, 1973) and is steadily available in a comparably consistent quality. Nevertheless, Hatt et al. (2005) showed that giraffes are unlikely to meet energy requirements with lucerne hay only. Some kind of non-forage component must be supplemented, which regularly contributes 50% of daily dry matter (DM) intake in giraffes (Hummel et al., 2006c). Thereby the fermentative behavior of non-forage feeds must be considered, as excessive amounts of energy providing ingredients like starch and sugar can lead to unphysiological conditions in the rumen (Van Soest et al., 1991). A catalogue of established concentrate feeds for giraffe nutrition is available (Hummel and Clauss, 2006), in which most pelleted compound feeds and dehydrated lucerne pellets are particularly suitable to meet requirements with sufficient extent of safety and consistence in terms of nutrient supply. This likewise applies to unmolassed sugar beet pulp as energy concentrate which is known for beneficial fermentation characteristics despite its high energy content (Van Soest et al., 1991).

In the course of feed intake documentation in giraffe facilities of twelve German zoos, a variety of samples of forage, concentrate feeds and produce (fruits and vegetables) was analysed for chemical composition and fermentation characteristics. The aim of the study was (1) to evaluate the quality of lucerne hay as prevailing forage source for giraffes and its resemblance to browse and (2) to approve recommendations on suitable feeds for captive giraffes concerning their composition and fermentative characteristics.

## MATERIAL AND METHODS

### Sample collection

A total of 196 feed samples was taken during 18 periods of feed intake documentation in the giraffe facilities of twelve German zoos located in Dortmund, Dresden, Duisburg, Frankfurt on the Main, Gelsenkirchen, Hanover, Cologne, Munster, Neunkirchen (Saar), Nuremberg, Schwerin and Stuttgart. Feed samples were sorted in categories of forage (n = 111) with browse leaves, browse bark, dried browse, lucerne hay, lucerne-grass-mixtures and further forage, and categories of non-forage feeds (n = 85) with compound feed, dehydrated lucerne pellets, pelleted browse-based product, sugar beet pulp, soya-bean meal (solvent-extracted), energy-rich cereal grain products, fibre-rich cereal grain products and produce. Single samples of grass hay and grass-clover hay were considered separately (Table 12).

**Table 12.** Terminology of categories of forage and non-forage feeds and number of samples collected during documentation periods in giraffe facilities of twelve German zoos

| Category of feed | Number of samples |
|---|---|
| *Forage* | |
| Browse leaves | 42 |
| Browse bark | 35 |
| Dried browse | 5 |
| Lucerne hay | 19 |
| Lucerne-grass mixture | 5 |
| Further forage | 3 |
| Nettle | |
| Jerusalem artichoke (overground part) | |
| Grass-clover hay | 1* |
| Grass hay | 1* |
| *Non-forage feed* | |
| Compound feed | 16 |
| Dehydrated lucerne pellets | 10 |
| Pelleted browse-based product | 3 |
| Sugar beet pulp | 9 |
| Soya-bean meal (solvent-extracted) | 6 |
| Energy-rich cereal grain products | 11 |
| Oat flakes | |
| Wheat flakes | |
| Maize grain | |
| Crispbread | |
| Rice | |
| Fibre-rich cereal grain products | 10 |
| Crushed oats | |
| Wheat bran | |
| Produce | 19 |
| Mixtures of fruits and vegetables | |
| Potatoes | |

*Excluded from statistical analysis (single samples only)

**General analyses**

All samples were milled through sieves of 1 mm pore size (forage: cutting mill SM 100, Retsch GmbH & Co. KG, Haan, Germany; others: centrifugal mill Retsch ZM 200, Retsch GmbH & Co. KG, Haan, Germany). Moist feeds were freeze-dried (Freeze-dryer P18K-E, Piatkowski Forschungsgeräte, München, Germany) before. Proximate analysis was done according to VDLUFA (2012), method numbers are given. The dry matter (DM) was determined by oven-drying of duplicate subsamples at 105°C (3.1). Ash and crude fat (CF) were analysed using methods 8.1 and 5.1.1. Crude protein (CP) was determined by Dumas combustion (4.1.2, Rapid N Cube, Elementar Analysesysteme GmbH, Hanau, Germany). Crude fibre was analysed according to method 6.1.1. Neutral detergent fibre (aNDFom, 6.5.1; assayed with heat stable amylase, expressed exclusive of residual ash), acid detergent fibre (ADFom, 6.5.2; expressed exclusive of residual ash) and acid detergent lignin (ADL, 6.5.3) were analysed using the Ankom A2000I Fiber analyzer system (Ankom Technology, Macedon, USA). According to point 8.8 of method 6.5.2, analysis of ADFom was done sequentially for lucerne products, beet pulp and produce as pectin-containing feedstuffs. Starch was estimated by an enzymatic method employing a heat-stable α-amylase (Termamyl 120 L; Novo Industrials, Bagsværd, Denmark) as a starch solubilising agent (Brandt et al., 1987).

### *In vitro*-gas production

The Hohenheim gas test (25.1) was conducted to measure the 24 hours (h) *in vitro*-gas production (GP) for estimation of metabolisable energy (ME) content and to measure GP over 96 h with readings at 2, 4, 8, 12, 24, 32, 48, 56, 72, 80 and 96 h of incubation. To consider effects of tannins on fermentation of browse, samples of leaves and bark were incubated both with and without polyethylene glycol (PEG) 6000 as substance being proven for its high affinity and capability to inert tannins (Makkar et al., 1995; Getachew et al., 2001).

### Calculations and statistical analysis

Estimation of ME content was done using best-fit equations according to the respective type of feed:

(1) ME ($MJ \cdot kg^{-1}$ DM) = 11.63 + 0.04837 × GP ($ml \cdot 200\ mg^{-1}$ DM) – 0.01256 × Ash ($g \cdot kg^{-1}$ DM) – 0.01228 × crude fibre ($g \cdot kg^{-1}$ DM) + 0.01435 × CF ($g \cdot kg^{-1}$ DM)
(Losand et al., 2014) for lucerne hay.

(2) ME ($MJ \cdot kg^{-1}$ DM) = 7.81 + 0.07559 × GP ($ml \cdot 200\ mg^{-1}$ DM) – 0.00384 × Ash ($g \cdot kg^{-1}$ DM) + 0.00565 × CP ($g \cdot kg^{-1}$ DM) + 0.01898 × CF ($g \cdot kg^{-1}$ DM) – 0.00831 × ADFom ($g \cdot kg^{-1}$ DM)
(GfE, 2008) for lucerne-grass-mixtures, grass hay and grass-clover hay.

(3) ME ($MJ \cdot kg^{-1}$ DM) = 2.20 + 0.1357 × GP ($ml \cdot 200\ mg^{-1}$ DM) + 0.0057 × CP ($g \cdot kg^{-1}$ DM) + 0.0002859 × $CF^2$ ($g \cdot kg^{-1}$ DM)

(Menke and Steingass, 1988) for browse, dehydrated lucerne pellets and further forage.

(4) ME (MJ · $kg^{-1}$ DM) = 7.17 + 0.06463 × GP (ml · 200 $mg^{-1}$ DM) − 0.01171 × Ash (g · $kg^{-1}$ DM) + 0.00712 × CP (g · $kg^{-1}$ DM) + 0.01657 × CF (g · $kg^{-1}$ DM) + 0.00200 × Starch (g·$kg^{-1}$ DM) – 0.00202 × ADFom (g · $kg^{-1}$ DM)
(GfE, 2009) for compound feed and pelleted browse-based product.

(5) ME (MJ · $kg^{-1}$ DM) = 1.06 + 0.1570 × GP (ml · 200 $mg^{-1}$ DM) + 0.0084 × CP (g · $kg^{-1}$ DM) + 0.0220 × CF (g · $kg^{-1}$ DM) – 0.0081 × Ash (g · $kg^{-1}$ DM)
(Menke and Steingass, 1988) for sugar beet pulp, soya-bean meal, energy-rich cereal grain products, fibre-rich cereal grain products and produce.

To consider different GP from tannin-containing forage under *in vitro*-conditions (Elahi et al., 2014), calculation of ME in browse was done using the average 24 h GP from incubation with and without PEG.

Estimation of fermentation parameters was done according to Ørskov and McDonald (1979) via non-linear regression in software program GraphPad PRISM 5 for Windows (GraphPad PRISM Software, Inc., La Jolla, California, USA) using the equation:

$y = a + b\,(1 - e^{-ct})$
(y = cumulative GP at point t, a = initial GP of soluble ingredients in the inoculum, b = potential GP of insoluble, fermentable ingredients in the inoculum, c = GP rate, a + b = maximum GP). Short time GP was specified as cumulative GP at two hours of incubation (GP2).

The theoretical 24 h GP distribution of exemplary rations was plotted depending on different non-forage portions of 5 kg DM (assumed as 50% of total daily DM intake) and a passage rate of particles of 4% · $h^{-1}$ (Clauss et al., 1998). The non-forage portion was either based on 50% produce with energy- or fibre-rich cereal grain products (25% each) (variation "produce"), or based on 50% sugar beet pulp with compound feed and dehydrated lucerne pellets (25% each) (variation "beet-pulp"). The non-forage portions were of similar ME (12.6 MJ ME · $kg^{-1}$ DM (± 0.3)) and CP content (125 g · $kg^{-1}$ DM (± 6.4)) (mean ± standard deviation), but of different aNDFom content with more aNDFom in "beet pulp" (399 g · $kg^{-1}$ DM) than in "produce" (204 g · $kg^{-1}$ DM). Feed intake was presumed to happen in two major meals per day at 08.00 and 16.00 h.

### Statistical analyses

For multiple comparisons of chemical composition and fermentation characteristics of feedstuffs, an analysis of variance was conducted using the GLM procedure in SAS 9.3 (SAS Institute Inc., Cary, North Carolina, USA). Category of feed was the fixed effect, and least squares means (ls mean) were compared using the Tukey test with differences considered significant at $p < 0.05$. For GP in browse, mean values from incubation with and without PEG served as data base. For a pairwise comparison of different GP from incubation with and without PEG, the student's t-test was used in SAS 9.3, with differences considered significant at $p < 0.05$.

## RESULTS

### Composition and fermentation of forage

The highest ME contents were shown for lucerne-grass mixture, lucerne hay and further forage (Table 13). Further forage, lucerne hay and dried browse had the highest values for CP. Compared to all other forages, browse bark showed a significantly lower content of ME and CP and a higher content of aNDFom, ADFom and ADL ($p < 0.001$). Compared to browse leaves, lucerne hay showed a greater content of ME ($p = 0.035$) and CP ($p = 0.002$) and a significantly lower ADL content ($p = 0.017$).

During fermentation (Table 13, Figure 2), gas was released with a rate of $5.5\% \cdot h^{-1}$ (dried browse) to $9.2\% \cdot h^{-1}$ (further forage). The GP2 and maximal GP in browse bark was lower compared to lucerne hay and lucerne-grass mixture ($p < 0.001$). Lucerne hay differed from browse leaves regarding GP rate ($p = 0.004$) and maximal GP ($p = 0.023$). PEG supplementation led to a significantly higher GP2, maximal GP and GP rate in browse (Table 14). Fitting of GP curves was particularly weak in browse leaves and browse bark.

The type of browse (Table 15; Appendix AII) showed an effect on contents of ME ($p = 0.026$), CF ($p < 0.001$), ash ($p < 0.001$) and ADL ($p = 0.021$), GP rate ($p = 0.002$) and maximal GP ($p = 0.005$) in browse leaves. Regarding samples of bark, the type of browse showed a significant effect on all variables of chemical composition (weakest $p = 0.007$) and fermentation (weakest $p = 0.004$).

**Table 13.** Contents of ME, CP, ash, CF and fibre fractions, results for GP2, maximal GP (a + b) and GP rate (c) (ls mean ± standard error) and $R^2$ of regression curves of forage; significant differences ($p < 0.05$) in lines are labeled with different letters

| | | Browse leaves | Browse bark | Dried browse | Lucerne hay | Lucerne-grass mixture | Further forage | Grass hay* | Grass-clover hay* |
|---|---|---|---|---|---|---|---|---|---|
| ME | $MJ \cdot kg^{-1}$ DM | 8.1 (0.2)$^{b}$ | 6.8 (0.2)$^{c}$ | 7.5 (0.4) | 8.9 (0.2)$^{a}$ | 9.2 (0.4)$^{ab}$ | 8.7 (0.6)$^{ab}$ | 7.1 | 9.8 |
| CP | $g \cdot kg^{-1}$ DM | 148 (4.5)$^{b}$ | 61.9 (4.9)$^{c}$ | 160 (13)$^{ab}$ | 179 (6.6)$^{a}$ | 148 (13)$^{ab}$ | 181 (17)$^{ab}$ | 90.0 | 119 |
| Ash | | 73.5 (3.7)$^{cd}$ | 62.3 (4.1)$^{d}$ | 78.6 (11)$^{bcd}$ | 104 (5.5)$^{b}$ | 96.9 (11)$^{abc}$ | 148 (14)$^{a}$ | 43.3 | 94.6 |
| CF | | 37.0 (2.9) | 26.9 (3.2) | 34.3 (8.4) | 25.7 (4.3) | 33.1 (8.4) | 23.0 (11) | 16.9 | 11.5 |
| aNDFom | | 449 (12)$^{b}$ | 568 (13)$^{a}$ | 393 (35)$^{b}$ | 454 (18)$^{b}$ | 482 (35) | 373 (45)$^{b}$ | 720 | 486 |
| ADFom | | 313 (9.6)$^{b}$ | 500 (10)$^{a}$ | 274 (28)$^{b}$ | 318 (14)$^{b}$ | 329 (28)$^{b}$ | 308 (36)$^{b}$ | 433 | 290 |
| ADL | | 141 (7.6)$^{b}$ | 236 (8.4)$^{a}$ | 90.3 (22)$^{bc}$ | 95.6 (11)$^{c}$ | 75.1 (22)$^{bc}$ | 61.1 (29)$^{bc}$ | 76.0 | 51.5 |
| GP2 | $ml \cdot 200\ mg^{-1}$ DM | 9.9 (0.3)$^{b}$ | 7.0 (0.3)$^{c}$ | 8.6 (0.9)$^{bc}$ | 11.4 (0.5)$^{ab}$ | 13.0 (0.9)$^{a}$ | 10.4 (1.2) | 5.4 | 12.7 |
| a + b | | 36.7 (1.1)$^{bc}$ | 32.2 (1.2)$^{c}$ | 38.6 (3.1) | 42.9 (1.6)$^{a}$ | 45.1 (3.1)$^{ab}$ | 40.4 (4.0) | 49.1 | 55.0 |
| c | $\% \cdot h^{-1}$ | 6.1 (0.3)$^{b}$ | 7.6 (0.4)$^{a}$ | 5.5 (1.0) | 8.3 (0.5)$^{a}$ | 6.5 (1.0) | 9.2 (1.3) | 3.0 | 7.2 |
| $R^2$ | % | 64.5 | 59.5 | 86.0 | 96.2 | 88.9 | 89.0 | 99.7 | 99.7 |

ME = metabolisable energy; CP = crude protein; CF = crude fat; aNDFom = neutral detergent fibre, assayed with heat stable amylase, expressed exclusive of residual ash; ADFom = acid detergent fibre, expressed exclusive of residual ash; ADL = acid detergent lignin; GP2 = cumulative gas production at 2 hours of incubation; DM = dry matter; * = excluded from statistical analyses (single samples only)

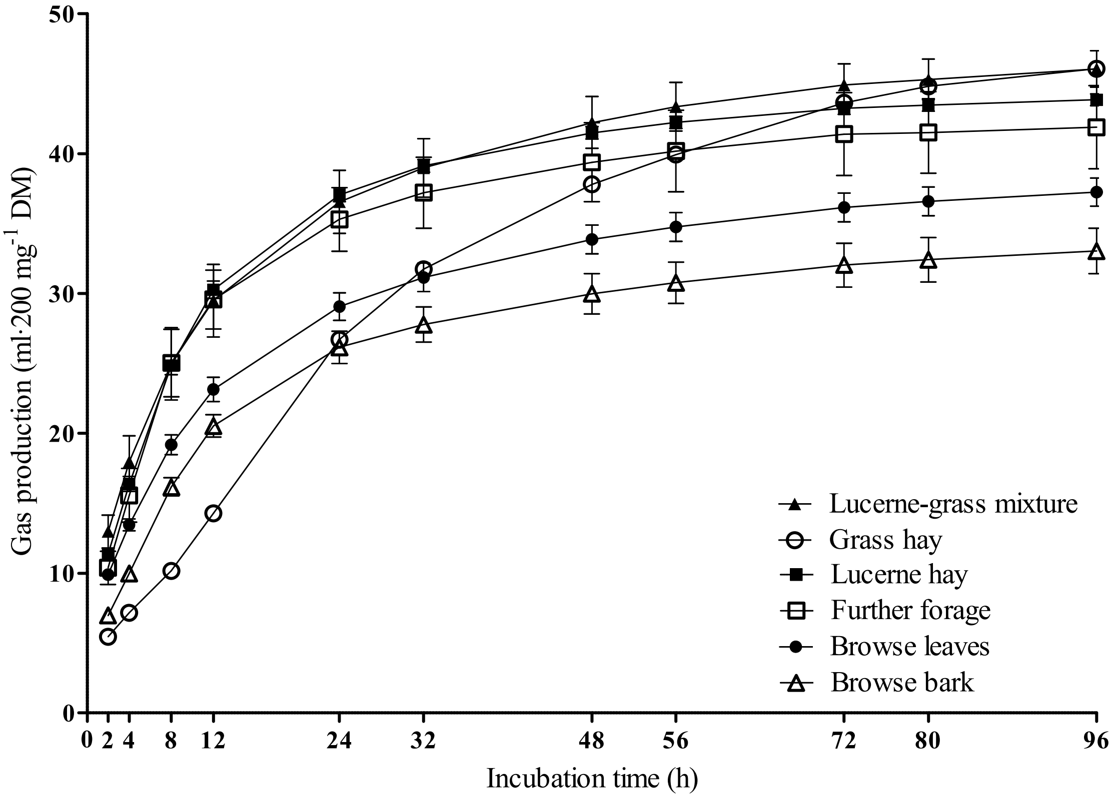


**Figure 2.** Fermentation pattern of forage over 96 hours of incubation in the Hohenheim gas test (mean ± standard error; values represent mean of gas production from incubation of browse leaves and browse bark with and without PEG supplementation)

**Table 14.** Cumulative GP (ml · 200 mg$^{-1}$ DM) at 2 hours of incubation (GP2), maximal GP (a + b; ml · 200 mg$^{-1}$ DM) and GP rate (c; % · h$^{-1}$) for browse leaves, browse bark and dried browse after incubation with or without PEG (mean ± standard deviation); significant increase is labeled with * ($p < 0.0001$), ** ($0.0001 \leq p < 0.01$) or *** ($0.01 \leq p < 0.05$)

| | Browse leaves | Increase | Browse bark | Increase | Dried browse | Increase |
|---|---|---|---|---|---|---|
| GP2 | 8.8 (2.2) | 23%* | 5.8 (2.1) | 38%* | 8.0 (2.9) | 15%*** |
| GP2 with PEG | 10.9 (2.2) | | 8.0 (1.8) | | 9.2 (2.8) | |
| a + b | 34.9 (7.2) | 10%* | 30.3 (9.6) | 13%* | 36.8 (5.1) | 13%** |
| a + b with PEG | 38.4 (6.1) | | 34.0 (9.9) | | 40.4 (4.5) | |
| c | 5.2 (1.9) | 32%* | 6.2 (2.1) | 43%* | 4.7 (0.7) | 36%** |
| c with PEG | 6.9 (1.9) | | 9.0 (4.1) | | 6.3 (0.4) | |

DM = dry matter; GP = gas production; PEG = polyethylene glycol

**Table 15.** Contents of ME ($MJ \cdot kg^{-1}$ DM), CP, ash, CF and fibre fractions (all in $g \cdot kg^{-1}$ DM), GP2 ($ml \cdot 200\ mg^{-1}$ DM), GP rate (c; $\% \cdot h^{-1}$) and maximal GP (a + b; $ml \cdot 200\ mg^{-1}$ DM) in the different types of browse leaves and bark (mean ± standard deviation); minimum and maximum values are given in bold per column

| | | ME | CP | Ash | CF | aNDFom | ADFom | ADL | GP2 | c | a + b |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Leaves* | | | | | | | | | | | |
| Ash | (n = 3) | 8.9 (0.6) | 150 (24) | 112 (4.6) | 33.0 (3.5) | 425 (12) | 289 (34) | 97.3 (7.4) | 12.6 (1.3) | 7.1 (0.8) | 44.0 (3.9) |
| Beech | (n = 5) | **6.7** (1.3) | 131 (24) | 52.7 (17) | 26.6 (7.0) | **507** (110) | **368** (102) | 156 (60) | **8.2** (1.9) | **4.7** (1.2) | 31.2 (7.5) |
| Birch | (n = 4) | 7.8 (0.6) | 159 (27) | 45.5 (11) | **78.3** (13) | 463 (34) | 330 (62) | **209** (30) | 9.1 (2.5) | 5.0 (0.7) | **26.6** (1.9) |
| Blackberry | (n = 1) | 9.2 | 163 | 63.1 | 41.7 | 344 | 223 | 71.4 | 11.9 | 6.6 | 44.5 |
| Cornus | (n = 1) | 9.1 | 136 | 112 | 45.5 | **213** | **157** | **46.1** | **14.5** | 7.6 | 42.9 |
| Elm | (n = 1) | **10.3** | **221** | 115 | 43.0 | 462 | 255 | 101 | 9.7 | **10.6** | **46.4** |
| Hazelnut | (n = 5) | 7.3 (0.5) | 137 (30) | 78.5 (14) | 25.0 (5.6) | 495 (37) | 298 (26) | 125 (19) | 9.3 (0.8) | 5.1 (0.5) | 36.5 (2.7) |
| Hornbeam | (n = 2) | 7.0 (1.7) | **122** (12) | **42.3** (4.5) | **16.8** (2.4) | 456 (160) | 328 (170) | 150 (119) | 11.9 (4.3) | 4.8 (1.5) | 33.8 (11) |
| Linden | (n = 2) | 8.6 (0.1) | 133 (9.2) | **125** (15) | 47.7 (9.2) | 482 (28) | 265 (13) | 111 (31) | 10.1 (0.7) | 7.2 (0.3) | 40.1 (3.2) |
| Maple | (n = 3) | 8.8 (0.2) | 144 (25) | 103 (9.5) | 49.3 (8.7) | 375 (32) | 279 (16) | 108 (12) | 10.4 (2.0) | 8.5 (1.0) | 39.5 (2.3) |
| Oak | (n = 5) | 7.6 (1.4) | 173 (37) | 50.0 (9.4) | 28.4 (12) | 456 (81) | 309 (55) | 141 (40) | 9.2 (1.6) | 5.0 (1.6) | 35.7 (6.7) |
| Red oak | (n = 2) | 8.6 (0.4) | 152 (17) | 48.1 (13) | 32.7 (3.8) | 416 (63) | 292 (2.8) | 125 (9.2) | 10.3 (2.0) | 8.1 (3.5) | 41.5 (0.4) |
| Robinia | (n = 2) | 7.7 (0.3) | 172 (26) | 95.1 (4.4) | 33.5 (3.5) | 425 (58) | 366 (90) | 171 (51) | 10.3 (1.0) | 5.9 (1.6) | 36.0 (0.7) |
| Sallow | (n = 5) | 7.9 (0.7) | 138 (21) | 77.0 (23) | 35.3 (7.1) | 398 (56) | 347 (50) | 190 (43) | 9.6 (2.2) | 6.6 (1.4) | 37.1 (3.7) |
| *Bark* | | | | | | | | | | | |
| Ash | (n = 2) | 8.5 (0.2) | 47.9 (1.3) | 69.6 (14) | 22.6 (1.8) | **427** (0.7) | **377** (2.1) | **105** (16) | 9.5 (0.7) | 5.5 (0.1) | 49.5 (0.6) |
| Beech | (n = 2) | 6.0 (0.1) | 45.7 (11) | 60.2 (13) | 12.9 (0.1) | 632 (5.0) | 555 (13) | 262 (8.5) | 6.0 (0.2) | 8.0 (0.9) | 27.2 (1.0) |
| Birch | (n = 5) | **5.5** (0.5) | **39.4** (2.7) | **31.7** (8.6) | 28.2 (11) | **633** (42) | 546 (23) | **303** (12) | 5.8 (0.5) | **13.5** (2.5) | **19.5** (2.4) |
| Elm | (n = 1) | **8.9** | 81.0 | 66.2 | 18.7 | 617 | 520 | 141 | **5.8** | 6.3 | **51.9** |
| Hazelnut | (n = 5) | 6.2 (0.2) | 64.1 (11) | 52.4 (7.0) | 16.8 (2.5) | 601 (20) | 536 (5.4) | 274 (23) | 6.2 (0.5) | 6.6 (0.8) | 28.8 (1.0) |
| Hornbeam | (n = 2) | 6.2 (0.02) | 49.4 (15) | 61.6 (35) | 16.5 (13) | 626 (8.5) | 550 (7.8) | 265 (23) | 5.9* | 8.0* | 27.7* |
| Linden | (n = 2) | 8.6 (1.2) | 44.2 (0.7) | **111** (40) | 55.1 (27) | 559 (78) | 418 (83) | 179 (13) | 6.8 (0.3) | 8.2 (0.6) | 37.6 (2.1) |
| Maple | (n = 3) | 7.1 (1.1) | 71.5 (16) | 83.4 (34) | **69.5** (78) | 548 (73) | 497 (59) | 243 (39) | 7.2 (0.7) | 8.6 (2.1) | 33.5 (7.9) |

**Table 15.** Continued

| | | ME | CP | Ash | CF | aNDFom | ADFom | ADL | GP2 | c | a + b |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Oak | (n = 5) | 5.7 (0.4) | 60.9 (13) | 53.1 (15) | 14.2 (7.4) | 592 (35) | 517 (57) | 264 (38) | 6.0 (1.2) | 5.9 (1.0) | 26.4 (5.1) |
| Read oak | (n = 1) | 6.9 | 53.5 | 55.3 | **12.3** | 600 | **566** | 220 | 7.6 | 9.8 | 32.9 |
| Robinia | (n = 2) | 7.3 (1.1) | **142** (5.7) | 89.1 (15) | 21.7 (0.4) | 550 (33) | 447 (9.9) | 172 (30) | **11.6** (2.3) | **5.1** (1.3) | 35.9 (8.1) |
| Sallow | (n = 5) | 7.4 (0.7) | 67.2 (28) | 68.0 (8.5) | 30.0 (5.1) | 461 (72) | 452 (85) | 201 (61) | 7.4 (2.6) | **5.1** (0.7) | 41.4 (4.3) |

ME = metabolisable energy; CP = crude protein; CF = crude fat; aNDFom = neutral detergent fibre, assayed with heat stable amylase, expressed exclusive of residual ash; ADFom = acid detergent fibre, expressed exclusive of residual ash, ADL = acid detergent lignin; *available for only one sample of hornbeam bark

**Composition and fermentation of non-forage feeds**

For non-forage feeds (Table 16), the lowest content of ME was shown in dehydrated lucerne pellets ($p < 0.001$), whereas energy-rich cereal grain products were highest in ME ($p = 0.012$; except compared to soya-bean meal). Sugar beet pulp, produce and the pelleted browse-based product showed comparably low CP contents, whereas the overall highest CP content was found for soya-bean meal ($p < 0.001$). Regarding fibre fractions, the lowest contents of aNDFom were shown in soya-bean meal, produce and energy-rich cereal grain products; the latter also showed the lowest overall content of ADFom ($p = 0.009$). The highest values for aNDFom were measured in dehydrated lucerne pellets, pelleted browse-based product and sugar beet pulp; the highest ADFom was shown in dehydrated lucerne pellets and pelleted browse-based product. Dehydrated lucerne pellets and sugar beet pulp contained the most ADL, whereas the other non-forage feeds showed ADL contents of similarly low levels.

Regarding fermentation (Table 16, Figure 3), the highest GP2 was shown in produce ($p < 0.001$). High-energy cereal grain products and sugar beet pulp showed the highest maximal GP, whereas it was lowest in dehydrated lucerne pellets ($p < 0.001$). The highest GP rate was estimated for sugar beet pulp ($p < 0.001$), whereas low GP rates were shown in compound feed, dehydrated lucerne pellets, pelleted browse-based product and fibre-rich cereal grain products.

Regarding the theoretical distribution of GP over 24 h depending on the type of non-forage part of ration (“produce” or “beet pulp”) (Figure 4), stronger GP peaks (+29% in the morning, +25% in the afternoon) occurred two hours after intake for “produce” and overall GP was higher (+12%) for this variation.

**Table 16.** Contents of ME, CP, ash, CF, fibre fractions and starch, results for GP2, maximal GP (a + b) and GP rate (c) (ls mean ± standard error) and $R^2$ of regression curves of non-forage feeds; significant differences ($p < 0.05$) in lines are labeled with different letters

| | | Compound feed | Dehydrated lucerne pellets | Pelleted browse-based product | Sugar beet pulp | Soya-bean meal (solvent-extracted) | Energy-rich cereal grain products | Fibre-rich cereal grain products | Produce |
|---|---|---|---|---|---|---|---|---|---|
| ME | $MJ \cdot kg^{-1}$ DM | 11.5 (0.1)$^{c}$ | 9.1 (0.2)$^{d}$ | 11.2 (0.3)$^{c}$ | 13.3 (0.2)$^{b}$ | 13.6 (0.2)$^{ab}$ | 14.2 (0.2)$^{a}$ | 10.9 (0.2)$^{c}$ | 13.1 (0.1)$^{b}$ |
| CP | $g \cdot kg^{-1}$ DM | 185 (6.5)$^{bc}$ | 168 (8.2)$^{c}$ | 99.4 (14)$^{ef}$ | 86.5 (8.6)$^{f}$ | 495 (11)$^{a}$ | 126 (7.8)$^{de}$ | 142 (8.2)$^{cd}$ | 103 (6.1)$^{ef}$ |
| Ash | | 93.3 (4.0)$^{b}$ | 127 (5.0)$^{a}$ | 51.3 (9.2)$^{cd}$ | 84.6 (5.3)$^{b}$ | 70.1 (6.5)$^{bc}$ | 19.8 (4.8)$^{d}$ | 40.0 (5.0)$^{d}$ | 78.8 (3.8)$^{bc}$ |
| CF | | 34.6 (2.6)$^{bc}$ | 35.9 (3.3)$^{ac}$ | 53.9 (6.0)$^{ab}$ | 21.8 (3.5)$^{cd}$ | 23.3 (4.3)$^{cd}$ | 48.5 (3.1)$^{a}$ | 49.1 (3.3)$^{a}$ | 22.2 (2.5)$^{d}$ |
| aNDFom | | 307 (18)$^{b}$ | 453 (22)$^{a}$ | 425 (41)$^{ab}$ | 427 (23)$^{a}$ | 199 (29)$^{c}$ | 156 (21)$^{c}$ | 393 (22)$^{ab}$ | 132 (17)$^{c}$ |
| ADFom | | 155 (11)$^{bc}$ | 306 (14)$^{a}$ | 223 (26)$^{ab}$ | 202 (15)$^{b}$ | 115 (18)$^{cd}$ | 32.2 (13)$^{e}$ | 146 (14)$^{bd}$ | 106 (10)$^{d}$ |
| ADL | | 31.2 (6.3)$^{c}$ | 83.9 (8.0)$^{ab}$ | 63.1 (15)$^{bc}$ | 118 (8.4)$^{a}$ | 19.6 (10)$^{c}$ | 15.4 (7.6)$^{c}$ | 43.2 (8.0)$^{c}$ | 27.5 (6.0)$^{c}$ |
| Starch | | 204 (21)$^{c}$ | 20.3 (26)$^{d}$ | 309 (48)$^{bc}$ | 11.2 (27)$^{d}$ | 11.9 (34)$^{d}$ | 730 (25)$^{a}$ | 375 (26)$^{b}$ | n.a. |
| GP2 | $ml \cdot 200\ mg^{-1}$ DM | 15.0 (0.9)$^{a}$ | 12.8 (1.1)$^{a}$ | 10.7 (2.1)$^{a}$ | 12.5 (1.2)$^{a}$ | 13.8 (1.5)$^{a}$ | 11.8 (1.1)$^{a}$ | 10.7 (1.1)$^{a}$ | 28.3 (0.8)$^{b}$ |
| a + b | | 60.9 (0.8)$^{c}$ | 43.4 (1.1)$^{e}$ | 52.0 (1.9)$^{d}$ | 73.8 (1.1)$^{ab}$ | 54.7 (1.3)$^{d}$ | 77.5 (1.0)$^{a}$ | 61.4 (1.1)$^{c}$ | 72.0 (0.8)$^{b}$ |
| c | $\% \cdot h^{-1}$ | 6.2 (0.4)$^{c}$ | 7.3 (0.4)$^{c}$ | 6.2 (0.8)$^{c}$ | 13.3 (0.4)$^{a}$ | 9.2 (0.5)$^{b}$ | 9.4 (0.4)$^{b}$ | 5.6 (0.4)$^{c}$ | 10.5 (0.3)$^{b}$ |
| $R^2$ | % | 93.5 | 92.8 | 98.7 | 97.2 | 98.7 | 97.6 | 96.5 | 91.9 |

ME = metabolisable energy; CP = crude protein; CF = crude fat; aNDFom = neutral detergent fibre, assayed with heat stable amylase, expressed exclusive of residual ash; ADFom = acid detergent fibre, expressed exclusive of residual ash; ADL = acid detergent lignin; GP2 = cumulative gas production at 2 hours of incubation; DM = dry matter; n.a. = not available

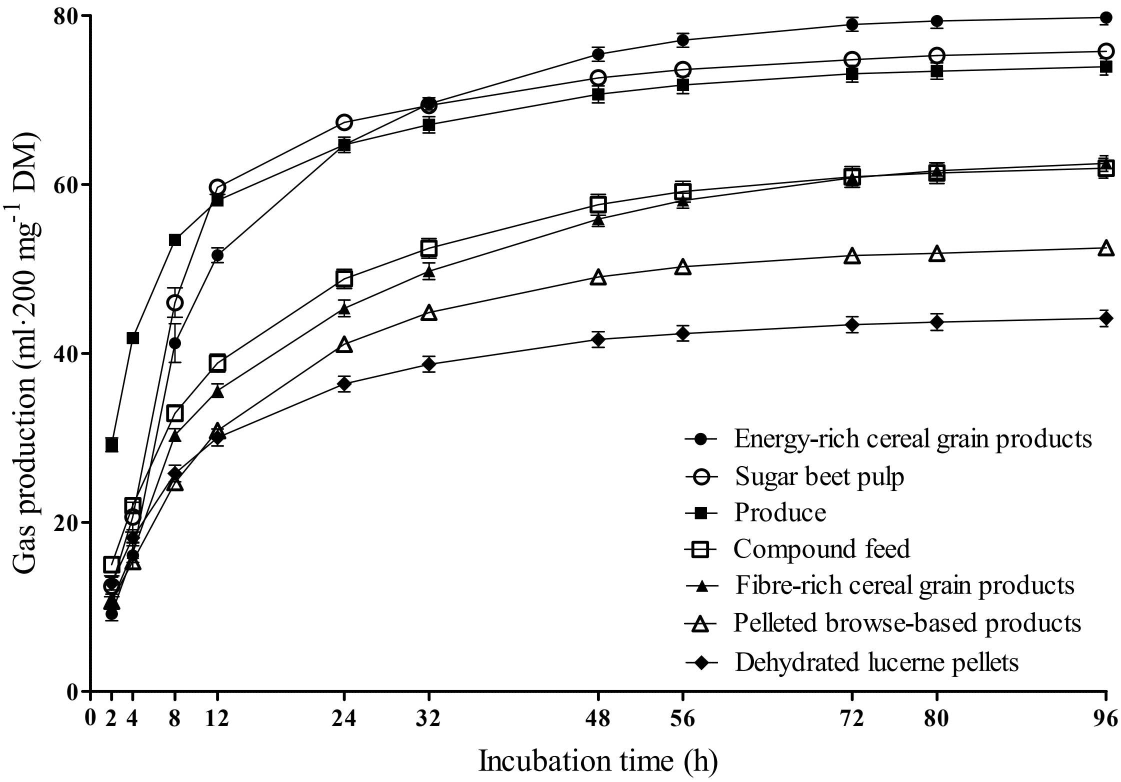


**Figure 3.** Fermentation pattern of non-forage feeds over 96 hours of incubation in the Hohenheim gas test (mean ± standard error)

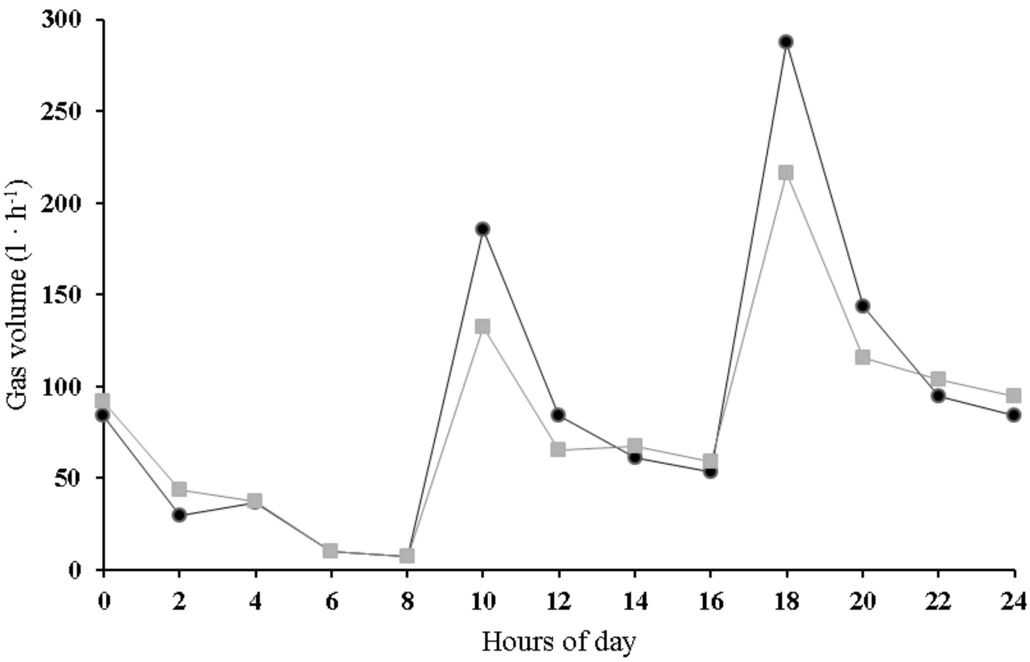


**Figure 4.** Theoretical course of gas production over 24 hours when feeding 5 kg of non-forage portion (DM) "produce" (●) or "beet pulp" (■)

## DISCUSSION

### Evaluation and quality of forage

#### *Quality of lucerne hay*

Lucerne hay was used as main forage source in the observed facilities. Unfortunately, information on maturity was not available; according to NRC (2001) it corresponded to legume hay of mid maturity (400-460 g NDF · $kg^{-1}$ DM). Compared with tabulated values on ruminant feeds (Universität Hohenheim – Dokumentationsstelle, 1997), lucerne hay was of good quality as judged from contents of ME, CP, ash and CF. The assumption of lucerne hay being a fibre source of stable quality was confirmed from this point. In literature on fibre fractions it was noticed that analytical methods for NDF and ADF were not concordantly done and/or stated regarding α-amylase treatment, ash correction and sequential analysis. As certain analytical differences must be considered when comparing analytical data, a higher consensus on nomenclature and methods in analysis of fibre is desirable.

#### *Lucerne hay vs. browse*

Besides high intake and availability, the suitability of lucerne hay as forage for captive giraffes is fixed to similarities in the chemical composition compared to browse. However, within the presently selected forages lucerne hay showed significant differences to browse leaves regarding content of ME (+9% in lucerne hay), CP (+17% in lucerne hay) and ADL (−47% in lucerne hay). Furthermore, maximal GP (+17%) and GP rate (+36%) were significantly higher in lucerne hay. As the present browse samples were of temperate type, information on the chemical composition and fermentative behavior of native *Acacia sp*. (Abdulrazak, 2000; Rubanza et al., 2005; Ondiek et al., 2010) was added to considerations (Table 17). Regarding aNDFom and ADFom content, lucerne hay accorded with the presently analysed temperate browse leaves. As high lignin contents are specific for browse, ADL content in temperate browse leaves was similar to *Acacia sp.* For CP content, lucerne hay matched better with *Acacia sp*. which was also true for maximum GP, but not for GP rate which was higher in lucerne hay than in temperate or indigenous browse. Finally, some conformity to temperate and indigenous browse underlined the status of lucerne hay as good alternative forage. Nevertheless, the suitability may not be fully confirmable based on similarities either to *Acacia sp.* or temperate browse as the species showed differences among themselves.

**Table 17.** Contents of ME, CP and fibre fractions, maximal GP (a + b) and GP rate (c) of browse leaves, browse bark and lucerne hay as presently analysed in comparison with literature data for *Acacia sp.*

| | | Browse leaves | Browse bark | Lucerne hay | *Acacia sp.*[1] |
|---|---|---|---|---|---|
| ME | MJ · $kg^{-1}$ DM | 7.9 | 6.7 | 8.9 | 7.4 |
| CP | g · $kg^{-1}$ DM | 148 | 61.9 | 179 | 182 |
| aNDFom | | 449 | 568 | 454 | 362[2] |
| ADFom | | 313 | 501 | 318 | 261 |
| ADL | | 141 | 236 | 95.7 | 117 |
| a + b | | 34.9 | 30.3 | 42.9 | 37.1 |
| c | % · $h^{-1}$ | 5.2 | 6.3 | 8.3 | 4.4 |

[1]According to Baumer, 1983; Abdulrazak et al., 2000; Rubanza et al., 2005; Ondiek et al., 2010; [2]given as NDFom; ME = metabolisable energy; CP = crude protein; aNDFom = neutral detergent fibre, assayed with heat stable amylase, expressed exclusive of residual ash; ADFom = acid detergent fibre, expressed exclusive of residual ash; ADL = acid detergent lignin, DM = dry matter

***Quality of temperate browse as forage***

The evaluation of fresh browse as inherent part of rations for giraffes is challenging. The chemical composition of browse samples as collected in the study varied considerably which may also explain the weakness of curve fitting in case of leaves and bark compared to the other feeds. The quality of leaves was less influenced by the type of browse than the quality of bark. Especially CP and fibre contents were more stable in leaves indicating a greater nutritional consistence. As bark showed the highest contents of ADFom and ADL, load of hardly or indigestible cell wall components from bark was high, whereas CP and ME contents were correspondingly low. Leafy branches and trees were usually bark-stripped in the observed facilities and intake of browse material from freshly cut branches and trees during winter was even reduced to woody material. Consequently, browse DM intake consisted of approximately 20% bark DM intake, equivalent to 1% of total DM intake. For comparison, in free-ranging giraffes the rumen ingesta consisted of 15% woody plant material (Owen-Smith, 1988), so the presently determined amounts of ingested bark would indicate a low risk of dietary inconsistency. Generally, the overall dietary contribution of browse portions was restrained to portions of 0 - 13% of dietary DM (Table 18). As zoo rations contain considerable amounts of high-protein forage and energy-rich concentrates (Hummel et al., 2006c), delivery of fibre from browse was of greater relevance than supply of energy or protein.

**Table 18.** Share of browse portions (%) in total intake of dry matter, energy and nutrients as consumed during documentation periods in giraffe facilities of twelve German zoos

| Period | Season | DM | ME | CP | aNDFom | ADFom | ADL |
|---|---|---|---|---|---|---|---|
| 1 | Winter | 2.8 | 1.3 | 0.8 | 4.3 | 3.7 | 4.0 |
| 2 | Winter | 9.0 | 6.8 | 6.2 | 8.6 | 11.7 | 13.7 |
| 3 | Winter | 2.6 | 2.2 | 2.5 | 2.4 | 2.6 | 2.5 |
| 4 | Winter | 4.8 | 3.6 | 3.4 | 5.0 | 6.2 | 14.1 |
| 5 | Winter | 4.3 | 3.5 | 4.6 | 4.9 | 4.9 | 5.3 |
| 6 | Summer | 11.3 | 7.2 | 8.8 | 15.0 | 18.8 | 28.5 |
| 7 | Summer | 1.2 | 0.8 | 1.1 | 1.4 | 1.3 | 1.9 |
| 8 | Summer | 12.1 | 10.7 | 10.6 | 12.0 | 13.3 | 19.8 |
| 9 | Summer | 1.7 | 1.3 | 1.3 | 2.0 | 2.2 | 2.2 |
| 10 | Summer | 13.1 | 9.4 | 11.3 | 15.2 | 17.2 | 23.5 |
| 11 | Summer | 10.3 | 7.2 | 7.4 | 12.8 | 17.3 | 28.1 |
| 12 | Summer | 2.4 | 2.1 | 2.3 | 2.4 | 2.7 | 4.7 |
| 13 | Summer | 9.2 | 7.8 | 6.6 | 9.2 | 11.7 | 17.0 |
| 14 | Summer | 5.2 | 4.6 | 5.7 | 7.1 | 7.4 | 10.5 |
| 15 | Summer | 11.1 | 6.7 | 7.2 | 14.2 | 16.4 | 24.4 |
| 16 | Summer | 12.4 | 9.2 | 9.9 | 14.2 | 15.4 | 22.9 |
| 17 | Summer | 5.5 | 4.7 | 4.1 | 5.3 | 5.5 | 7.7 |

ME = metabolisable energy, CP = crude protein, aNDFom = neutral detergent fibre, assayed with heat stable amylase, expressed exclusive of residual ash, ADFom = acid detergent fibre, expressed exclusive of residual ash, ADL = acid detergent lignin; DM = dry matter

Browse contains high amounts of secondary plant compounds like tannins (Rubanza et al., 2005). Browsers are adapted to these by secretion of tannin-binding salivary proteins (Robbins et al., 1987a; Austin et al., 1989). Tannin-binding proteins were lacking under respective *in vitro*-conditions, as rumen fluid needed to be taken from sheep as grazing ruminants, not producing any tannin-binding substances even if tannin-containing diets were fed (Ammar et al., 2011). Consequently, it appeared debatable how accurate GP of tannin-containing forage was simulated for a browsing ruminant. The effectivity of tannin-inhibition *in vivo* is highly complex (Elahi et al., 2012), and a pure quantitative analysis of contents of phenolic substances was supposed to lack validity. In contrast, the incubation of tannin-containing forage with PEG as tannin-binding substance is capable to mitigate adverse effects of tannins on fermentation (Getachev et al., 2001) and the percentage increase in gas value correlates with the tannin content (Makkar et al., 1995). Consequently, the use of PEG as substitute for tannin-specific proteins during *in vitro*-fermentation was valued as most reliable way to consider peculiarities during *in vivo*-fermentation of browse in browsers. However, it must be considered that the extent of transferability of effects of PEG or tannin-binding salivary proteins on fermentation remains unsettled. An equal consideration of GP measured with and without PEG supplementation was an attempt to prevent under- or overestimated potential effects of PEG to evaluate fermentation of tannin-containing forage as solid as possible.

**Evaluation and quality of non-forage feeds**

As poor body condition and fat atrophy occurred in captive giraffes (Clauss et al., 2006), insufficient energy and nutrient supply is an issue. With grinding and pelleting of forage its density can be increased resulting in a higher intake and more rapid passage of insoluble matter (Van Soest, 1994). Dehydrated lucerne pellets fully fitted to the chemical composition and fermentation pattern of lucerne hay and offered supplementation of additional fermentable fibre and CP. However, it lacked physical structural properties, was thus sorted as non-forage feed and can not be exclusively used as fibre source. Additional completing of rations was possible with feeds of higher energy content. As the usage of concentrate feeders or total mixed rations is irrelevant in practical giraffe nutrition, intake of non-forage feeds happened during very few times per day in respective large amounts. Therefore, an even, moderate GP of energy providing non-forage feeds was highly desirable. Present compound feeds showed an overall moderateness in nutrient composition and fermentation. A similar GP rate compared to browse leaves suggested GP in higher quantities, but with likewise uniformity. Provision of additional energy happened with produce, energy-rich cereal grain products and sugar beet pulp. Produce includes high amounts of soluble nonstructural carbohydrate (i.e., sugar) (Van Soest et al., 1991; Schmidt et al., 2005). In energy-rich cereal grain products energy is mainly provided as starch which also belongs to the nonstructural carbohydrates, but shows a more ambiguous solubility (Van Soest et al., 1991). Much of the energy in sugar beet pulp is based on pectins, an easily fermentable constituent of the cell wall (Van Soest et al., 1991; Van Soest, 1994) representing approximately 10 - 20% of DM in beet pulp (Michel et al., 1985; Phatak et al., 1988). Although maximum GP was similar among the high-energy feeds, produce generated an immediate short time GP (Figure 5). In contrast, short time fermentation in energy-rich cereal grain products and sugar beet pulp was delayed, thus GP happened in similar rates, but less ’explosive’ (Oftedal et al., 1996). In concordance to that, theoretical additive distribution of GP over 24 h showed stronger peaks immediately after intake of variation “produce” (Figure 4).

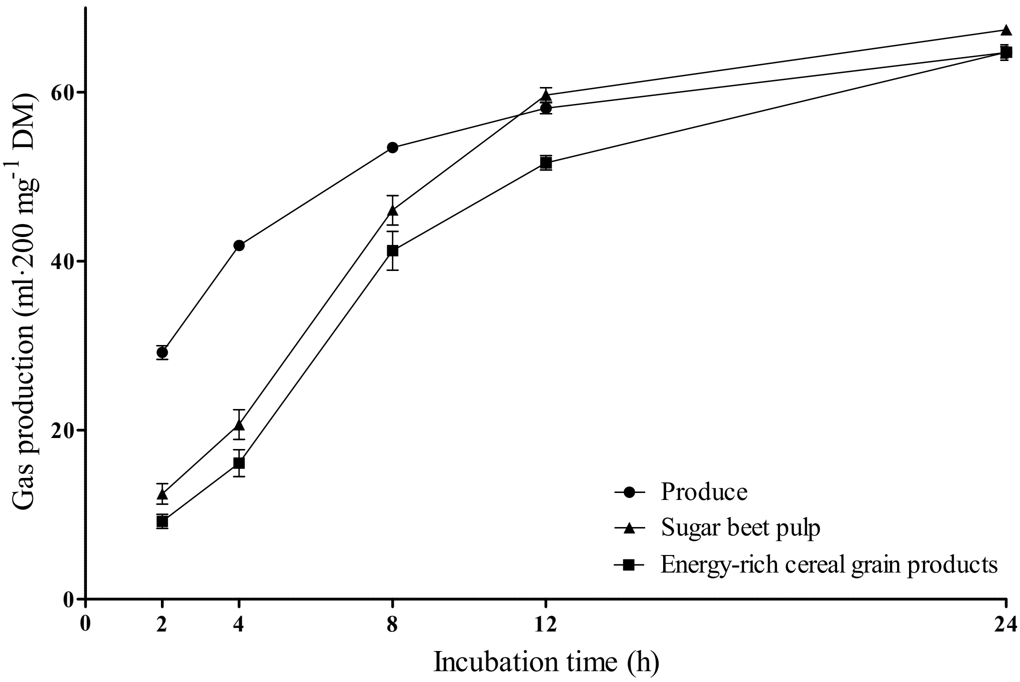


**Figure 5.** Pattern of gas production of energy providing feedstuffs at 2, 4, 8, 12, and 24 hours of incubation in the Hohenheim gas test (mean ± standard error)

Differences between starch and pectin fermentation occur with regard to acid load. The risk to induce acidosis and a potential switch from acetate to lactate production during fermentation is higher for starch (Van Soest et al., 1991; Odongo et al., 2006). In contrast, the structure of galacturonic acid in pectins provides buffering potential through cation exchange capacity and metal ion binding (Van Soest et al., 1991). An exchange of grains with beet pulp showed a significant increase of rumen pH and acetate concentration in cows (Mahjoubi et al., 2009). Presently, a theoretical replacement of non-forage portion “produce” with “beet pulp” led to an overall lower and more even GP without less energy or protein content in the non-forage proportion, but with provision of additional aNDFom. Ultimately, the interest of providing suitable non-forage feeds with least negative input on rumen fermentation increases with increasing dietary proportion of non-forage feeds. As energy concentrates generally put higher pressure on rumen pH than forage, among present high-energy feeds sugar beet pulp showed the most preferable preconditions to maintain rumen conditions balanced.

**Protein supply in captive giraffes**

Sufficient CP supply with *ad libitum* provision of lucerne hay may work with higher certainty than widely expected. The CP content in the present lucerne hay was higher and CP precipitation from tannins and fibre-binding from lignification was expected to be absent or much lower than in browse. In zoo studies, CP intake was mostly sufficient to cover estimated requirements or rather reach values given from free-range studies (e.g. Baer et al., 1985; Hatt et al., 2005; Pellew, 1984). Nevertheless, feeds high in CP were regularly used in addition. To try a new perspective, the term ruminal nitrogen balance (RNB) of the German protein evaluation system for dairy cows (GfE, 2001) was introduced which is used to evaluate nitrogen supply to ruminal microbes and optimise protein use efficiency. It compares ruminal input (N in feed) and output (ruminal outflow of microbial and undegraded N). Lack of ruminal N (negative RNB) may retard fermentation and microbial synthesis; an overspill (positive RNB) leads to high urinary N excretion and less effective protein utilisation (Lebzien et al., 2006). Feeds should be combined in a ration resulting in a RNB close to zero (GfE, 2001). For lucerne hay of comparable CP content, an RNB input of +8 $g \cdot kg^{-1}$ DM is given (LfL, 2015). There is reason to query whether the RNB in captive giraffe likely tilts over in positive ranges with lucerne hay being supplied as major ration component. Consequentially, there was no need to provide non-forage feeds for the purpose of protein supply. Any negative compensation to the RNB would have been delivered only with high-energy non-forage feeds, with sugar beet pulp permitting energy with the least additional supply of CP.

## CONCLUSIONS

Analyses of forage showed that lucerne hay being fed in twelve German zoos was of stable quality and chemical composition and fermentative behaviour showed general accordance with browse. Therefore, lucerne hay presented a good agreement between certain similarities to browse and the necessity of high acceptance in giraffes. Temperate browse showed a large variation of qualities according to type, and supplementation of PEG as tannin-binding agent led to a greater *in vitro*-GP. Of the non-forage feeds, dehydrated lucerne pellets largely resembled lucerne hay, and compound feeds showed a desirable overall 'middlingness' regarding composition and fermentation. The suitability of sugar beet pulp was accredited due to advantages in GP and a lower ruminal acid load compared to sugar- or starch-based products. Overall, recommendations on suitable feedstuffs for captive giraffes were confirmed. However, the protein value of lucerne hay, if provided for *ad libitum* intake in a proper quality, should not be underrated when composing non-forage feed portions.

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# CHAPTER 5

## Influence of ration composition on nutritive and digestive variables in captive giraffes (*Giraffa camelopardalis*) indicating the appropriateness of feeding practice

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Prepared for submission

## SUMMARY

The nutrition of captive giraffe (*Giraffa camelopardalis*), a browsing ruminant, is challenging because browse availability is limited in zoos and rations need to be composed from compensatory feeds. In this study, ration composition in giraffe facilities of twelve German zoos was documented and linked to animal variables that indicate suitability of nutrition. Rations differed in proportion and chemical composition resulting in various grades of concordance with feeding recommendations. A metabolisable energy (ME) intake (MEI) (mean ± SD) of 0.6 MJ ME/kg metabolic body size (kg $BW^{0.75}$) (± 0.1) was estimated and sufficient to cover ME requirements. Mean dry matter (DM) intake (DMI) was 61 g DM/kg $BW^{0.75}$ (± 10), showing a negative correlation to the dietary ME content ($p = 0.009$; $r = -0.596$). Feed intake was regulated by energetic satiety and not by physical properties of forage. A negative correlation between produce proportion and DMI ($p = 0.002$; $r = -0.676$) led to the assumption of acidotic ruminal conditions in the giraffes. Increasing dietary forage proportions led to an increasing duration of feed intake activity ($p = 0.045$; $r = 0.477$) and decreasing occurrence of oral stereotypies ($p = 0.047$; $r = -0.474$). The weighted average particle size in faeces was larger than reported for free-ranging giraffes, but relations to ration characteristics among the facilities were not observed. The abrasiveness of rations was not excessive, as contents of silicate in faeces were similar to values from free-range. Body condition was overall acceptable with some animals tending to slimness and no evident relation to ration characteristics. The capacity to self-regulate DMI and MEI with intake of lucerne hay may work with higher reliability than expected for captive giraffes. Rations with less energetic density can result in a greater DMI in giraffes, for the benefit of a desirably high intake of forage.

**Key words**: body condition, browser, feed intake, faecal particle size, forage proportion, oral stereotypies

## INTRODUCTION

Giraffes (*Giraffa camelopardalis*) are moderately selective, but purely browsing ruminants (Van Soest, 1988; Hofmann, 1989; Steuer et al., 2014). They developed adaptations to physical and chemical peculiarities of browse. The chemical composition of cell walls and physical structure of leaves are of particular interest, as browse cell walls contain less slowly degradable, but more easily degradable and undegradable constituents than temperate grasses (Bailey, 1964; Nastis and Malecheck, 1981; Tolera et al., 1997). Reticular venation and high lignin contents lead to high fragility and small polygonal fragments during particle breakdown (Moseley and Jones, 1984; Spalinger et al., 1986). Sooner maximum energy release (Hummel et al., 2006c) and smaller, less bulky particles finally lead to shorter ingesta retention times and lack of stratification in the rumen of browsers (Hofmann, 1989; Clauss and Lechner-Doll, 2001; Hummel et al., 2005; Clauss et al., 2009a; Clauss et al., 2009b; Codron and Clauss, 2010). Furthermore, plant defense mechanisms lead to different strategies in animals: As grasses contain high silica levels (McNaughton et al., 1985), grazers evolved high molar crowns (Archer and Sanson, 2002) and excrete silicate-binding salivary proteins (Mau et al., 2013). In contrast, browse contains high amounts of secondary plant compounds (Palo, 1985) and browsers excrete tannin-binding salivary proteins (Robbins et al., 1987; Austin et al., 1989).

As browse availability is limited in zoos of the temperate zone, compensatory feeds need to be supplied. However, species-specific adaptations of the giraffe influence intake, comminution and digestibility of compensatory feeds. Information on appropriate ration composition is available, but browsers are generally more challenging to feed and demonstrate a higher nutrition-related mortality in captivity than grazing ruminants (Müller et al., 2011). Some disorders and phenomena in giraffes are known for their relation to nutrition: (1) Captive giraffes tend to show poor body condition or rather serous fat atrophy, caused by insufficient feed and energy intake (Potter and Clauss, 2005; Clauss et al., 2006); (2) occasionally captive giraffes suffer from typical feeding related disorders in ruminants like acidosis and laminitis being related to rations high in concentrate feeds (Clauss et al., 2002b; Wiedner et al., 2014); (3) heavier tooth wear was observed in captive compared to free-ranging giraffe (Clauss et al., 2007) caused by higher abrasiveness of zoo rations (Kaiser et al., 2009); (4) captive giraffes excrete larger faecal particles compared to free-ranging giraffes (Fritz, 2007) indicating a less effective particle size reduction capacity in terms of zoo rations (Hummel et al., 2008) and (5) the frequency of feeding and ration composition influenced feed intake activity and the occurrence of oral stereotypies in captive giraffes (Bashaw et al., 2001; Baxter and Plowman, 2001; Hummel et al., 2006a).

Uncertainties concerning appropriate ration composition, sufficient energy supply and intake regulatory mechanisms in giraffe exist and it remains questionable how rations exert influence on physiology and health. The aim of the study was to evaluate potential influences of different rations on indicators that are known for their relation to the above mentioned phenomena and disorders in captive giraffe. The variability in practical feeding was used to relate composition and quality of numerous rations to feed and energy intake, silica content in faeces, faecal particle size, body condition and behaviour in terms of feed intake activity and oral stereotypies as animal variables. Findings were supposed to give new insights into consequences and impact of practical giraffe feeding and may increase general knowledge on the nutrition of browsing ruminants in zoos.

## MATERIAL AND METHODS

### Documentation periods

Data were generated with groups of giraffes in twelve German zoos. Six zoos located in Cologne, Dortmund, Frankfurt on the Main, Gelsenkirchen, Hanover and Muenster were visited during winter and summer season. Another six zoos located in Dresden, Duisburg, Neunkirchen (Saar), Nuremberg, Schwerin and Stuttgart were visited during summer season only. In total 18 documentation periods took place from November 2011 to September 2013. Age and reproductive status (gestation, lactation) of 95 observed animals was known. Body weights (BW) were estimated in intervals of 25 kg, according to existing data of BW development in giraffes by Reason and Laird (2004) and actual weights of animals in one zoo being quantified with a scale (Table 19).

**Table 19.** Sex and number, mean age (± SD), mean metabolic body size (kg $BW^{0.75}$) (± SD), mean performance factor and mean ration composition for the groups of giraffes with overall sum or mean (± SD) as documented during 18 documentation periods in twelve German zoos

| Period | Season | Group information | | | | Ration composition | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Sex and number of animals | Group age (± SD) years | Group kg $BW^{0.75}$ (± SD) kg | Performance factor | Forage* % of ration DM | Browse | Concentrate | Produce |
| 1 | Winter | m† = 3, f‡ = 3 | 5.8 (4.9) | 121 (39) | 1.21 | 49.9 | 2.8 | 42.0 | 5.3 |
| 2 | Summer | m = 3, f = 2 | 5.5 (5.7) | 101 (46) | 1.20 | 36.1 | 11.3 | 48.0 | 4.6 |
| 3 | Winter | m = 4, f = 4 | 6.0 (5.0) | 117 (37) | 1.05 | 43.0 | 9.0 | 42.8 | 5.2 |
| 4 | Summer | m = 5, f = 4 | 5.8 (5.1) | 114 (39) | 1.18 | 42.6 | 12.1 | 39.7 | 5.6 |
| 5 | Winter | m = 2, f = 2 | 7.8 (6.6) | 123 (34) | 1.06 | 53.6 | 2.6 | 42.2 | 1.6 |
| 6 | Summer | m = 2, f = 2 | 8.2 (6.6) | 132 (60) | 1.10 | 54.5 | 1.2 | 42.7 | 1.6 |
| 7 | Winter | m = 1, f = 5 | 10.9 (4.2) | 140 (4.0) | 1.04 | 26.5 | 4.8 | 68.3 | 0.4 |
| 8 | Summer | m = 2, f = 5 | 9.8 (4.3) | 142 (7.9) | 1.00 | 32.9 | 13.4 | 53.1 | 0.6 |
| 9 | Winter | m = 3, f = 2 | 9.7 (10.2) | 132 (60) | 1.13 | 63.7 | 0.0 | 35.4 | 0.9 |
| 10 | Summer | m = 3, f = 2 | 9.5 (10.2) | 129 (67) | 1.13 | 50.3 | 10.3 | 38.3 | 1.1 |
| 11 | Winter | m = 3, f = 5 | 9.8 (8.0) | 121 (40) | 1.37 | 69.1 | 4.3 | 24.6 | 2.0 |
| 12 | Summer | m = 3, f = 5 | 8.9 (8.2) | 119 (46) | 1.15 | 66.2 | 2.3 | 29.2 | 2.3 |
| 13 | Summer | m = 1, f = 3 | 7.2 (6.4) | 118 (42) | 1.17 | 49.6 | 1.6 | 30.7 | 18.1 |
| 14 | Summer | m = 1, f = 3 | 7.7 (4.7) | 147 (9.7) | 1.00 | 64.6 | 9.3 | 26.1 | 0.0 |
| 15 | Summer | f = 2 | 8.6 (8.2) | 142 (7.6) | 1.00 | 28.7 | 5.2 | 55.5 | 10.6 |
| 16 | Summer | m = 2 | 6.6 (0.6) | 159 (2.4) | 1.00 | 55.6 | 11.1 | 28.2 | 5.1 |
| 17 | Summer | m = 2 | 6.1 (0.4) | 166 (7.2) | 1.00 | 56.6 | 12.4 | 17.7 | 4.3 |
| 18 | Summer | m = 4, f = 2 | 4.5 (5.4) | 100 (54) | 1.09 | 46.8 | 5.5 | 44.5 | 3.2 |
| | | ∑ m = 44, f = 51 | Ø 7.7 (1.8) | 129 (18) | 1.10 (0.1) | 49.5 (13) | 6.6 (4.5) | 39.4 (12) | 4.0 (4.4) |

* Hay and moist forage out of racks; † male; ‡ female

**Dry matter and energy intake**

Dry matter (DM) intake (DMI) was measured group-wise during documentation periods by weighing provided feedstuffs and residues on five consecutive days with concurrent determination of DM of offered and refused feeds (duplicate subsamples pre-dried at 60°C and dried at 105°C; method 3.1, VDULFA, 2012). To compare DMI between documentation periods, it was expressed as g DMI per kg metabolic body size (kg $BW^{0.75}$) per group, based on a daily maintenance metabolisable energy (ME) requirement of 0.50 MJ ME/kg $BW^{0.75}$ (Pellew, 1984). Requirements of gestating, lactating or growing animals were considered by allocating performance factors which indicated a potential additional DMI per kg $BW^{0.75}$ due to the status of performance (Table 20). The factors were derived from data on energy requirement ante and post partum in dairy cows or for weight gain in bovine calves (GfE, 2001) and the metabolic body size of each animal was multiplied by the respective factor. Correspondingly, ME intake (MEI) was standardised to intake of MJ ME/kg $BW^{0.75}$ of groups.

**Table 20.** Factors indicating additional dry matter intake based on higher requirements due to status of performance (gestation, lactation or growth)

| Adult female | | | | Juvenile | |
|---|---|---|---|---|---|
| Months of gestation | Factor* | Months of lactation | Factor* | Age in months | Factor* |
| 0.0- 8.0 | 1.00 | 0.0- 3.0 | 1.82 | 0.0- 3.0 | 0.00 |
| 9.0-10.7 | 1.09 | 4.0- 6.0 | 1.82 | 4.0- 6.0 | 0.40 |
| 10.8-12.4 | 1.15 | 7.0- 9.0 | 1.63 | 7.0- 9.0 | 0.75 |
| 12.5-14.0 | 1.29 | 10.0-12.0 | 1.34 | 10.0-12.0 | 1.06 |
| | | | | 13.0-15.0 | 1.41 |
| | | | | 16.0-18.0 | 1.34 |
| | | | | 19.0-21.0 | 1.35 |
| | | | | 22.0-30.0 | 1.27 |
| | | | | ≥ 31.0 | 1.00 |

*was multiplied with metabolic body size of respective animal

**Analysis of feedstuffs**

Representative samples of all feedstuffs were taken during documentation periods. Samples (numbers in parentheses) belonged to the category of forage with lucerne hay (19), grass hay (1), grass-clover hay (1), lucerne-grass mixture (5), nettle (2), Jerusalem artichoke (overground part) (1), fresh leaves (42), fresh bark (35) and dried browse (5), and the category of non-forage feeds with compound feeds (16), dehydrated lucerne pellets (10), straight feeding stuffs (grain products (21), sugar beet pulp (9) and solvent-extracted soya-bean meal (6)), pelleted browse-based product (3) and mixtures of produce (fruits and vegetables) (19). Samples were milled through a sieve of 1-mm pore size (forage: hammer mill SM 100, Retsch GmbH & Co. KG, Haan, Germany; pelleted feeds, straight feeding stuffs, produce: centrifugal mill Retsch ZM 200, Retsch GmbH & Co. KG, Haan, Germany). Moist feedstuffs were freeze-dried before (model P18K-E, Piatkowski Forschungsgeräte, München, Germany). Proximate analysis was done according to VDLUFA (2012) and method numbers are given. Ash and crude fat (CF) were analysed using methods 8.1 and 6.1.1. Crude protein (CP) was determined by Dumas combustion (4.1.2, Rapid N Cube, Elementar Analysesysteme GmbH, Hanau, Germany). Crude fibre was analysed according to method 6.1.1. Neutral detergent fibre (aNDFom; 6.5.1; assayed with heat stable amylase, expressed exclusive of residual ash), acid detergent fibre (ADFom; 6.5.2; expressed exclusive of residual ash) and acid detergent lignin (ADL; 6.5.3) were analysed using Ankom A2000I Automated Fiber analyzer (Ankom Technology, Macedon, USA). According to point 8.8 of method 6.5.2, analysis of ADFom was done sequentially for pectin containing lucerne products, sugar beet pulp and produce. Acid detergent insoluble ash ($ADIA_{Feed}$) was quantified as residual ash after treatment in acid detergent solution during ADFom analysis. Starch was estimated by an enzymatic method employing a heat-stable α-amylase (Termamyl 120 L; Novo Industrials, Bagsværd, Denmark) as a starch solubilising agent (Brandt et al., 1987).

The Hohenheim gas test (VDLUFA, 2012, method 25.1) was conducted to measure the 24 h *in vitro*-gas production (GP) for estimation of ME content. Samples of browse were incubated both with and without polyethylene glycol (PEG) 6000 as proven tannin-complexing agent to consider effects of tannins on fermentation in ruminants (Robbins et al., 1987; Getachew et al., 2001). Subsequently, estimation of ME for samples of leaves and bark was done using the average 24 h GP from incubation with and without supplementation of PEG to consider different GP from tannin-containing forage as solid as possible.

Estimation of ME content was done using the following best-fit equations according to the respective type of feed:

(1) ME (MJ/kg DM) = 11.63 + 0.04837 × GP (ml/200 mg DM) – 0.01256 × Ash (g/kg DM) – 0.01228 × crude fibre (g/kg DM) + 0.01435 × CF (g/kg DM)
(Losand et al., 2014) for lucerne hay;

(2) ME (MJ/kg DM) = 7.81 + 0.07559 × GP (ml/200 mg DM) – 0.00384 × Ash (g/kg DM) + 0.00565 × CP (g/kg DM) + 0.01898 × CF (g/kg DM) – 0.00831 × ADFom (g/kg DM)
(GfE, 2008) for grass-clover-hay, grass hay and lucerne-grass-mixture;

(3) ME (MJ/kg DM) = 2.20 + 0.1357 × GP (ml/200 mg DM) + 0.0057 × CP (g/kg DM) + 0.0002859 × $CF^2$ (g/kg DM)
(Menke and Steingass, 1988) for browse leaves and bark, dehydrated lucerne pellets and further forage;

(4) ME (MJ/kg DM) = 7.17 + 0.06463 × GP (ml/200 mg DM) − 0.01171 × Ash (g/kg DM) + 0.00712 × CP (g/kg DM) + 0.01657 × CF (g/kg DM) + 0.00200 × Starch (g/kg DM) – 0.00202 × ADFom (g/kg DM)
(GfE, 2009) for compound feeds and pelleted browse-based product;

(5) ME (MJ/kg DM) = 1.06 + 0.1570 × GP (ml/200 mg DM) + 0.0084 × CP (g/kg DM) + 0.0220 × CF (g/kg DM) – 0.0081 × Ash (g/kg DM)
(Menke and Steingass, 1988) for straight feeding stuffs and produce.

**Analyses of faecal samples**

Two samples of faeces per animal were collected on two separate days. For estimation of faecal particle size, duplicate samples (5 - 10 g) were wet sieved for 10 minutes through sieves of 16, 8, 4, 2, 1, 0.5, 0.25, 0.125 and 0.063 mm mesh size according to Kovács et al. (1997). Before sieving, samples were soaked with aqua dest. and stirred overnight. Sieving was conducted using an electromagnetic sieve shaker (Retsch Vibrotonic VE 1, Retsch GmbH & Co. KG, Haan, Germany) with a water flow of 2 l/min sprayed on the top sieve and with an amplitude adjusted at 2 mm. Material retained on the sieves was washed on pre-weighed filter paper (MN 640 m, Macherey-Nagel, Düren, Germany), dried overnight at 60°C and then dried at 105°C for one hour. Before weighing back, filters were stored next to the scale for several hours for equilibration with air humidity. To consider changes of air humidity, two filters per run served as blank value. The weighted average particle size (WAPS) (Fritz, 2007) was chosen to define particle size as mean size of retained particles on a sieve of specific mesh size using the equation:

WAPS = Fraction on sieve y (%) × averaged mesh size of sieves (y + 1) and y (mm)/100.

Prior to analysis of faecal CP and ADIA ($ADIA_{Faeces}$), samples per animal were mixed and reduced to small particles using a hand-held blender (Kenwood Home Appliance HB 615 400 W, Kenwood Limited, Havant, Hampshire, UK). Faecal CP (nitrogen (N) × 6.25) was determined on undried samples using the standard Kjeldahl procedure (VDLUFA, 2012, method 4.1.1; distillation system Vapodest 50s, Gerhardt GmbH & Co. KG, Königswinter, Germany) and used to estimate organic matter (OM) digestibility of rations with equation:

OM digestibility = $79.76 - 107.7e^{(0.01515 \times \text{faecal CP (g/kg OM)})}$ (Lukas et al., 2005).

For determination of $ADIA_{Faeces}$, samples were freeze-dried (model P18K-E, Piatkowski Forschungsgeräte, München, Germany), milled through a sieve of 1-mm pore size (centrifugal mill Retsch ZM200, Retsch GmbH & Co. KG, Haan, Germany) and $ADIA_{Faeces}$ was quantified as residual ash after treatment in acid detergent solution.

**Body condition scoring**

For estimation of body condition score (BCS) the system by Kearney and Ball (2001) was used. Scores from 1 to 8 were assigned to very poor body condition (1), poor body condition (2), slim but sufficient body condition (3), good body condition with little visible fat reservoirs (4), good body condition (5), good body condition with tendency to overweight (6), overweight (7) and obesity (8).

**Observation of behaviour**

The behavioural pattern of each animal was observed during a total of six observation periods, with two periods being conducted on each of three consecutive days. The first period of the day was conducted in the morning, starting one hour after feeding time and/or lock out into the enclosure. The second period of the day was conducted in the afternoon, starting two hours before feeding time and/or penning into the stable. Observation periods took 60 minutes; every minute the behaviour of each individual was documented. Documentation focused on forage intake activity (intake of hay or moist forage out of racks, provided for *ad libitum* intake), browse intake activity (intake from restrictively provided trees and branches or from vegetation in/around the enclosure), rumination and stereotypic activity as appearance of oral stereotypies (licking on objects, tongue playing).

### Statistical analysis

A data set based on documentation periods ($n = 18$) was combined from information on feeding practice by implementing a combined effect from the factors zoo and season (zooseas). For this data set, arithmetic means were created for ration characteristics (composition and quality variables) and intake variables (DMI, MEI). For animal variables (WAPS, $ADIA_{Faeces}$, BCS, OM digestibility and variables on behaviour) least squares means (ls mean) were created using the GLM procedure in SAS (Version 9.3, SAS Institute Inc, Cary, North Carolina, USA), considering zooseas, age, sex and/or status as fixed factors. With PROC CORR, correlations between ration characteristics and animal variables were tested; Pearson's correlation coefficient was reported as indicator of strength and direction of relationships. Potential linear or square relationships between DMI and ration characteristics were tested using PROC REG. Seasonal effects on animal variables and ration characteristics ($n = 12$ for summer; $n = 6$ for winter) were tested with the CONTRAST statement. To evaluate factors influencing the occurrence of oral stereotypies, the PROC GLM was conducted for the variables licking and tongue playing as binary, animal-specific data. Results for effects, correlations, orthogonal contrasts and linear relations were considered significant at $p < 0.05$. For correlations and effects, results were considered as a trend at $0.05 \leq p < 1.0$.

## RESULTS

### Ration composition and quality

Mean proportions of 57% forage, 39% concentrates and 4% produce in ration DM were determined (Table 21). Forage comprised 6.6% of fresh or preserved browse. Regarding fibre fractions, mean dietary concentrations of 401 g aNDFom/kg DM, 260 g ADFom/kg DM and 80.7 g ADL/kg DM were determined; a mean value of 10.8 g/kg DM was measured for $ADIA_{Feed}$. On average, the rations contained 162 g CP/kg DM and 10.1 MJ ME/kg DM. The OM digestibility of rations was 71.8% (ls mean). Effects of documentation period were observed for proportion of forage, concentrates and produce, content of aNDFom, ADFom and ME in rations and the OM digestibility. Seasonal effects were shown for OM digestibility (+1.0% in summer), browse proportion (+4.5% of ration DM in summer) and $ADIA_{Feed}$ (+4.94 g/kg DM in winter).

**Table 21.** Results for ration composition, animal variables and effects (p-value) of documentation period or season on ration composition and animal variables

| | | Mean/ *Ls mean* | SD/ *SE* | Min. | Max. | Effect of Period | Effect of Season |
|---|---|---|---|---|---|---|---|
| **Ration characteristics** | | | | | | | |
| Forage | % of ration DM | 49.5 | 13 | 27 | 69 | 0.016 | 0.844 |
| Concentrate | | 39.4 | 12 | 18 | 68 | 0.021 | 0.831 |
| Produce | | 4.0 | 4.4 | 0.1 | 18 | < 0.001 | 0.699 |
| Browse | | 6.6 | 4.5 | 0.0 | 13 | 0.432 | 0.095 |
| aNDFom | g/kg ration DM | 401 | 40 | 318 | 460 | 0.057 | 0.192 |
| ADFom | | 260 | 39 | 193 | 321 | 0.049 | 0.518 |
| ADL | | 80.7 | 16 | 53.1 | 107 | 0.164 | 0.616 |
| $ADIA_{Feed}$ | | 10.8 | 3.9 | 5.90 | 19.9 | 0.878 | 0.099 |
| CP | | 162 | 8.1 | 144 | 182 | 0.468 | 0.361 |
| Ash | | 87.9 | 9.9 | 68.8 | 101 | 0.759 | 0.238 |
| CF | | 31.4 | 6.6 | 24.0 | 51.8 | 0.731 | 0.318 |
| ME | MJ/kg ration DM | 10.1 | 0.7 | 9.14 | 11.4 | < 0.001 | 0.108 |
| OM digestibility | % | *71.8* | *0.83* | 68.6 | 75.7 | < 0.001 | 0.005 |
| **Animal variables** | | | | | | | |
| DMI | g/kg $BW^{0.75}$ | 61 | 10 | 40 | 78 | 0.043 | 0.040 |
| MEI | MJ/kg $BW^{0.75}$ | 0.6 | 0.1 | 0.45 | 0.8 | 0.150 | 0.032 |
| WAPS | mm | *1.06* | *0.11* | 0.62 | 1.35 | < 0.001 | 0.645 |
| $ADIA_{Faeces}$ | g/kg DM | *26.9* | *4.40* | 13.9 | 42.1 | 0.033 | 0.188 |
| BCS | Points | *4.3* | *0.21* | 3.7 | 4.9 | < 0.001 | 0.706 |
| Forage intake ac. | % of | *19* | *4.6* | 1.2 | 42 | < 0.001 | 0.312 |
| Browse intake ac. | observation | *11* | *4.1* | 0.0 | 23 | 0.037 | 0.342 |
| Rumination | time | *23* | *4.5* | 8.0 | 41 | < 0.001 | 0.007 |
| Stereotypic ac. | | *4.7* | *3.6* | 0.0 | 14 | 0.387 | 0.363 |

aNDFom = neutral detergent fibre, assayed with heat stable amylase, expressed exclusive of residual ash; ADFom = acid detergent fibre, expressed exclusive of residual ash; ADL = acid detergent lignin; $ADIA_{Feed}$ = acid detergent insoluble ash in feed; CP = crude protein; CF = crude fat; ME = metabolisable energy; OM = organic matter; DMI = dry matter intake; MEI = metabolisable energy intake; WAPS = weighted average particle size; $ADIA_{Faeces}$ = acid detergent insoluble ash in faeces; BCS = body condition score; DM = dry matter; ac. = activity

### Animal variables

A mean DMI of 61 g/kg $BW^{0.75}$ and a mean MEI of 0.6 MJ/kg $BW^{0.75}$ were estimated (Table 21). The WAPS (ls mean = 1.06 mm) showed a linear increase with increasing age of giraffes ($p < 0.001$). The ls mean for $ADIA_{Faeces}$ was 26.9 g/kg DM and for BCS 4.3 points. The animals spent 19% of observation time with forage intake activity, 11% with browse intake activity and 23% with rumination. Oral stereotypies occurred during 4.7% of observation time. Documentation period exerted an effect on DMI, WAPS, $ADIA_{Faeces}$, BCS, forage intake activity, browse intake activity and rumination. Seasonal effects were significant for DMI (+7.6 g/kg $BW^{0.75}$ in winter), MEI (+0.1 MJ/kg $BW^{0.75}$ in winter) and rumination (+8.5% of observation time in summer).

Licking on objects was observed in 32% of the animals with an effect of sex ($p = 0.019$; 80% licking by females). Tongue playing occurred in 10% of the animals, of which 89% were females; age ($p < 0.001$) and status of performance ($p = 0.052$) also had influence.

**Correlations and interactions**

The DMI and MEI were positively correlated ($p < 0.001$). An increasing forage proportion tended to increase DMI ($p = 0.065$); an increasing dietary ME content resulted in a decrease of DMI ($p = 0.009$) (Table 22). The ME content and DMI concordantly showed a linear relationship ($p = 0.001$; $R^2 = 0.355$) (Figure 6).

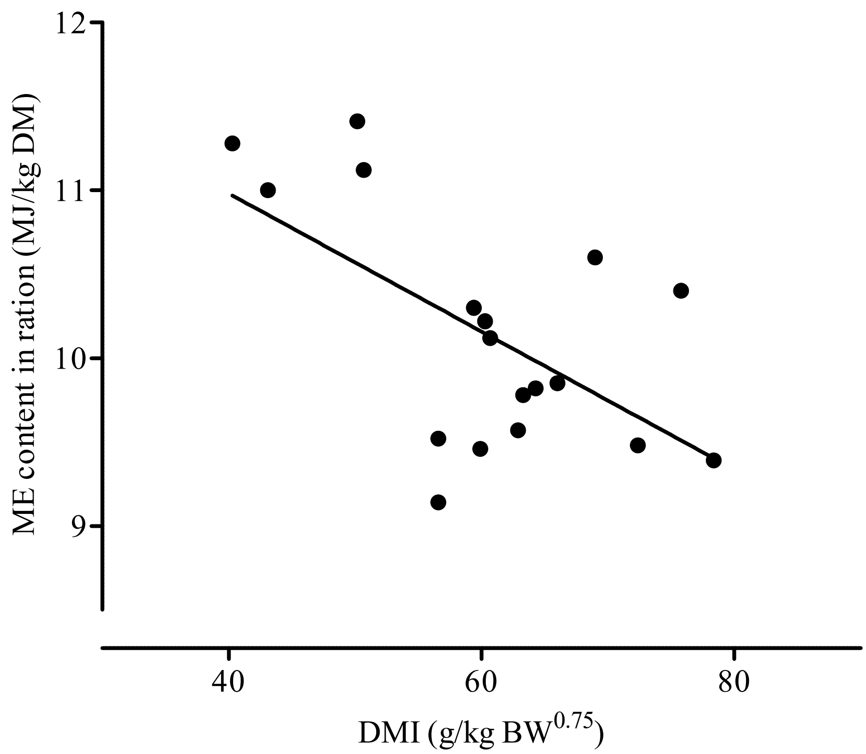


**Figure 6.** Relationship between dry matter intake (DMI) during documentation periods (n = 18) and content of metabolisable energy (ME) in rations; $y = 12.6 – 0.04 x$; $R^2 = 0.355$; $p = 0.001$

The proportion of produce showed a negative relation to the DMI ($p = 0.002$) and MEI ($p = 0.006$) (Table 22), with DMI also being linearly related to the proportion of produce in ration ($p = 0.002$; $R^2 = 0.456$) (Figure 7). The content of $ADIA_{Faeces}$ decreased with increasing DMI ($p = 0.007$). Forage intake activity was prolonged with an increasing dietary forage proportion ($p = 0.011$) and reduced with increasing dietary proportion of concentrate ($p = 0.006$). The occurrence of oral stereotypies increased with increasing dietary concentrate proportion ($p = 0.052$) and decreased with increasing dietary forage proportion ($p = 0.047$).

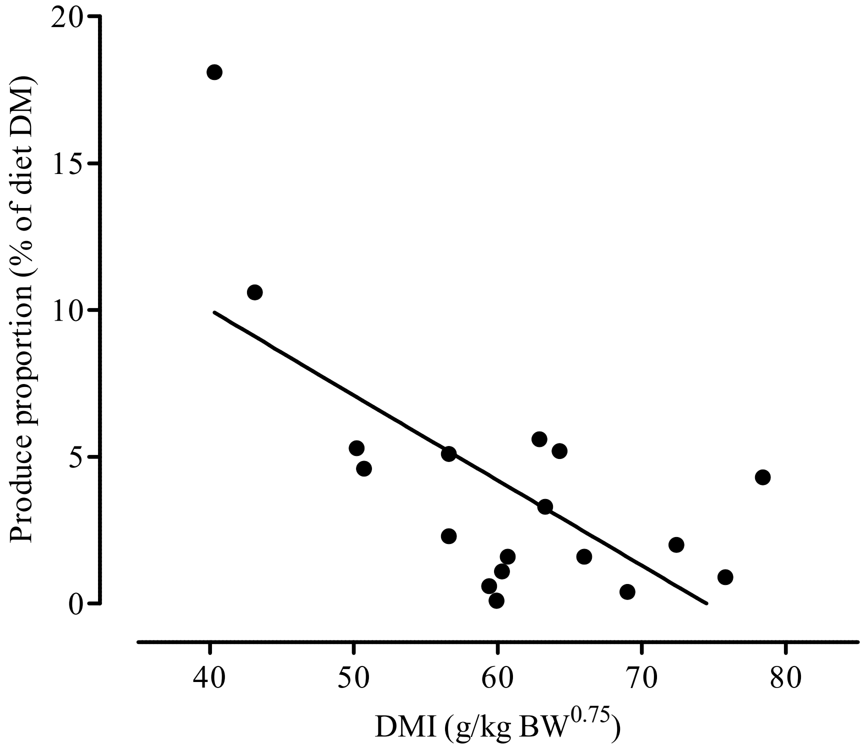


**Figure 7.** Relationship between dry matter intake (DMI) during documentation periods ($n = 18$) and proportion of produce in the rations; $y = 21.6 – 0.29 x$; $R^2 = 0.456$; $p = 0.002$

**Table 22.** Correlation coefficients between ration composition (dietary proportion and concentrations) and animal variables

| | p < 0.01 | | 0.01 ≤ p ≤ 0.05 | | 0.05 < p < 1.0 | |
|---|---|---|---|---|---|---|
| **Proportion of** | | | | | | |
| Forage | | | Forage intake ac. | 0.477 | DMI | 0.446 |
| | | | Stereotypic ac. | −0.474 | | |
| Concentrate | | | Forage intake ac. | −0.540 | | |
| | | | Stereotypic ac. | 0.468 | | |
| Produce | DMI | −0.676 | | | | |
| | MEI | −0.620 | | | | |
| | $ADIA_{Faeces}$ | 0.648 | | | | |
| Browse | | | | | $ADIA_{Faeces}$ | −0.406 |
| | | | | | Browse intake ac. | 0.417 |
| **Concentration of** | | | | | | |
| aNDFom | | | | | $ADIA_{Faeces}$ | −0.443 |
| | | | | | Browse intake ac. | 0.454 |
| ADFom | | | $ADIA_{Faeces}$ | −0.578 | DMI | 0.455 |
| | | | | | Browse intake ac. | 0.413 |
| ADL | | | Forage intake ac. | 0.527 | $ADIA_{Faeces}$ | −0.406 |
| CP | | | | | DMI | −0.460 |
| | | | | | $ADIA_{Faeces}$ | 0.444 |
| ME | DMI | −0.596 | | | Stereotypic ac. | 0.451 |
| | $ADIA_{Faeces}$ | 0.598 | | | | |
| Ash | | | DMI | 0.489 | MEI | 0.438 |

DMI = dry matter intake; MEI = metabolisable energy intake; $ADIA_{Faeces}$ = acid detergent insoluble ash in faeces; aNDFom = neutral detergent fibre, assayed with heat stable amylase, expressed exclusive of residual ash; ADFom = acid detergent fibre, expressed exclusive of residual ash; ADL = acid detergent lignin; CP = crude protein; ME = metabolisable energy; ac. = activity

## DISCUSSION

### Ration composition and recommendations

As rations differed in proportion and nutrient composition, recommendations were met to different degrees. On average a desired target of at least 50% forage in ration DM (Hummel and Clauss, 2006) was achieved, but forage proportion fell below the limit during four documentation periods; during another four, the critical value was marginally exceeded. Correspondingly, the proportion of non-forage feeds was partly higher than 50% of ration DM, showing a considerable range for concentrate and produce proportion. Feeding of produce should be restricted to at most 5% of ration DM and for special purposes (Hummel and Clauss, 2006). An average concentration of 4% fruits and vegetables in ration DM was marginal, but as daily inherent part of rations its use did not correspond to recommendations. Except for one documentation period, browse was regularly supplied as fresh branches or trees (85% of browse DM intake), dried browse (13% of browse DM intake) or frozen browse (2% of browse DM intake). Browse intake consisted of approximately 80% leafy and 20% woody material (bark and twigs). As the supply of fresh browse in temperate zone is only realisable during summer, more browse was provided and consumed during summer. Ration composition was likely sufficient to meet recommendations of CP supply (> 14% of ration DM; Schmidt and Kendrick, 2009), which was not a critical variable. Recommended concentrations of fibre fractions (> 400 g NDFom/kg DM (Schmidt and Kendrick, 2009), 250-300 g ADFom/kg DM (Schmidt and Schlegel, 2005)) were reached on average, but showed fluctuating values according to the varying dietary proportions. Mean estimated OM digestibility was similar to rations with 50% lucerne hay, 44% concentrates and 6% produce as determined *in vivo* on goats (I. Gussek, J. Steinhoff-Wagner, J. Hummel, K.-H. Südekum, unpublished data). Present mean and ranges of DMI were in line with literature data on giraffe and okapi (Clauss et al., 2001; Hatt et al., 2005; Hummel et al., 2005). The same was true for mean and range of MEI which was in line with data on energy intake in captive giraffes offered rations of lucerne hay, concentrate and browse (Hatt et al., 2005) and sufficient to cover energy requirements (Pellew, 1984).

**Ration composition and animal variables**

***Dry matter and energy intake***

High forage intake is highly desirable in ruminants (Van Soest, 1994), but was not consistently observed in the giraffes of this study, even though forage was provided for *ad libitum* intake. Therefore, it may be questioned which dietary characteristics primarily regulated feed intake. Intake of rations with high digestibility and energy density is continuously increasing up to a point of energetic satiety independent from gut fill (Conrad, 1966; Van Soest, 1994). In case of less digestible, bulky rations with low energy density, feed intake is constantly increasing until regulated through maximal distension of the digestive tract (Conrad, 1966; Van Soest, 1994). As the results revealed a positive relationship of DMI with dietary ADFom content and a negative relationship with dietary ME content (Figure 6), it is likely that the giraffes did not consume as much feed as gut capacity would allow. Prior to an intake regulation due to physical feed properties, dietary energetic density limited DMI. Furthermore, maximal DMI as transition point between energetic and physical regulation of DMI was suggested at a lower OM digestibility than presently determined (Conrad, 1966). The offered non-forage portions were completely consumed during 12 of 18 documentation periods, where certain restriction of feed intake must have happened at the expense of forage intake. Animals in six facilities showed larger left-overs of 8 - 50% of DM of the provided non-forage portion. As the energetic value of these rations was above the mean ME content, it was assumable that energetic satiety again served as regulating factor and feed intake restriction even applied to non-forage feeds.

It remains questionable at which point structure or quality of compensatory forage would limit DMI and whether forage intake was limited in the first place due to different fragility, particle breakdown, particle passage and digestibility of compensatory forage (McLeod and Minson, 1988; Hummel et al., 2008; Clauss et al., 2011). As high forage quality enables high forage DMI in cattle (Van Soest, 1965) and captive browsers (Taylor et al., 2013), quality attributes of lucerne hay relative to DMI were separately tested (Table 23). Only CP content of lucerne hay allowed a satisfactory prediction of DMI in giraffes. However, a negative slope was observed, concordantly with the overall negative relationship of CP content in ration with DMI. Although intake regulation by gut fill may work at lesser volumes in captive browsers than in captive grazers (Clauss and Lechner-Doll, 2001), physical properties of compensatory forage was not a limiting factor in DMI in the giraffes of this study, as nutrient metabolism affected regulation prior to that. To reach an ME intake of 0.6 MJ/kg $BW^{0.75}$ exclusively from lucerne hay (mean estimated ME content of 8.9 MJ/kg DM), an adult giraffe of 800 kg would need to eat 10.4 kg DM. A necessary DMI of 69 g DM/kg $BW^{0.75}$ was above the mean estimated DMI, but inside the range, not indicating quantitatively significant intake limitation. However, Hatt et al., (2005) showed that zoo giraffes were not able to cover energy requirements when fed solely on lucerne hay and a limitation of lucerne hay intake in giraffes due to limited comminution and digestion capacities in case of large amounts still seem likely.

**Table 23.** Assessment of dry matter intake in giraffes based on regression analysis of quality parameters in lucerne hay as provided during documentation periods in twelve German zoos

| Predictor | Intercept | SE | Slope | SE | p-value |
|---|---|---|---|---|---|
| Dietary ME | 85.04 | 38.15 | −2.645 | 4.301 | 0.548 |
| Dietary CP | 120.9 | 19.85 | −0.336 | 0.112 | 0.009 |
| Dietary aNDFom | 76.44 | 28.82 | −0.032 | 0.063 | 0.614 |
| Dietary ADFom | 44.28 | 20.71 | 0.053 | 0.063 | 0.413 |

ME = metabolisable energy; CP = crude protein; aNDFom = neutral detergent fibre, assayed with heat stable amylase, expressed exclusive of residual ash; ADFom = acid detergent fibre, expressed exclusive of residual ash; SE = standard error

High contents of ME and CP were not instrumental in achieving sufficient MEI in the giraffes. The DMI and MEI were significantly higher in winter, whereas the dietary ME content was constant across seasons. As the non-forage feeds were almost completely consumed throughout the year, increasing DMI was primarily due to greater forage intake. Giving scope for a greater self-regulation of MEI through forage intake may work with higher reliability in giraffes compared to browsers of smaller body size, e.g. moose (Clauss et al., 2002a), as giraffes forage with a lower grade of selectivity and are more tolerant towards forage of varying quality (Demment and Van Soest, 1985; Owen-Smith, 1988; Clauss et al., 2014).

It should be noted that most studies on DMI in giraffes used values quantified for individuals, whereas presently DMI was reported for several, heterogeneous groups of giraffes. Intensive control on data collection in separately kept single animals and a preferably large sample size are hardly combinable in zoo animals. An estimation of BW is affected by uncertainty, even if conducted consequently by one single person, and actual weights would have been highly desirable. However, by allocating performance factors to animals representing different physiological stages (Table 20), comparability of data was achieved. As the corrected data on DMI and MEI were in line with literature data it was assumed that documentation of feed intake in groups of giraffe works sufficiently if the individual status of performance of the animals in groups is considered.

### *Acidogenic potential of rations*

Concentrates alone had no effect on DMI or MEI, but DMI and MEI showed a negative correlation and linear relation with the proportion of produce (Figure 7). Produce obviously affected DMI and MEI, potentially induced by more than just high energy content, but the major chemical form of energy which is easily fermentable sugar (Schmidt et al., 2005). As a result, fruits and vegetables show an acidogenicity value that is 50% and 100% higher compared to compound feeds or willow leaves, indicating a high potential to cause ruminal acidosis (Odongo et al., 2006). A negative relationship between produce proportion and DMI indicated acidotic conditions in the rumen and a reduction of DMI may likewise have resulted from a lowered appetite due to gastrointestinal discomfort. However, without measurement of ruminal pH, acidotic conditions can only be speculated and low average dietary produce proportions necessitate careful interpretation of results. Nevertheless, as lack of advantage of feeding fruits and vegetables to captive browsers has been communicated before (Hummel and Clauss, 2006), the results should be taken as additional indication of produce feeding being expendable.

***Faecal particle size***

A disability of giraffes to comminute feed in captivity as effective as in the wild was reported (Clauss et al., 2007) and primarily founded on dentition being largely adapted to the physicochemical characteristics of browse (Archer and Sanson, 2002; Hummel et al., 2008). As the WAPS in the present giraffes (1.06 ± 0.11 (ls mean ± SE)) was larger compared to values reported from free-range (0.44 ± 0.03 (mean ± SD)) (Clauss et al., 2002c; Hummel et al., 2008), the present rations showed a limited nativeness regarding physicochemical characteristics. However, no effects of ration composition on WAPS in the present giraffes were observed, even though amounts of finely-ground concentrate or browse differed. An interpretation of different WAPS among captive giraffes with regard to nutrition appeared not reliable, as physicochemical characteristics of compensatory forage and its influence on comminution and digestion may superpose effects of any dietary variation on faecal particle size in captive giraffes.

***Silicates in feed and faeces***

The development of hypsodonty and mesowear signature in ruminants is consistent with the classification of feeding types (Fortelius and Solounias, 2000) and grades of abrasiveness of feed, as hypsodonty index and faecal silica levels are positively correlated (Hummel et al., 2011). Silica, ingested as plant constituent (phytoliths) or adhesion (grit, soil), is harder than tooth enamel and leads to dental abrasion (McNaughton et al., 1985). Excessive tooth wear was reported for captive browsers and giraffes compared to free-ranging individuals (Clauss et al., 2007; Kaiser et al., 2009; Hummel et al., 2011). The content of $ADIA_{Faeces}$ in the giraffes of the study (26.9 g/kg DM ± 4.40 (ls mean ± SE)) was similar to values determined for free-ranging giraffes during wet season (24 g/kg DM ± 11 (mean ± SD)) (Hummel et al., 2011). From this perspective, the abrasive load of rations was not excessive. Even though contents of $ADIA_{Faeces}$ differed among the giraffes, no relationship was observed to $ADIA_{Feed}$. The intake of undefinable amounts of external silica from the ground or as adhesion cannot be ruled out and a negative correlation of DMI to $ADIA_{Faeces}$ were suggestive of a diluting effect.

***Body condition***

A BCS of 4.3 points was determined for the giraffes, indicating an acceptable nutritional condition. However, most animals showed little visible fat reservoirs; 19% of the animals were valued with a BCS lower than 4, indicating poor body condition. Age had an effect ($p = 0.001$), with animals < 3.7 years generally showing BCS > 4. As status or sex had no effect on BCS, productive animals, non-productive animals, males and females were equally distributed at the lower end of the BCS scale. Additional pressure on giraffes with little fat reservoirs may arise from particular susceptibility to cold stress in temperate zones, as suggested by Clauss et al. (1999). Giraffes evolved thermoregulatory mechanisms mostly to achieve heat losses in their natural environment (Mitchell and Skinner, 2004), which is why low energy reserves and higher energy demands in colder temperatures may cause collapses of giraffes (Potter and Clauss, 2005). To consider the risk of cold stress, temperature loggers were placed in the stables during winter documentation periods (measurement from 01 January to 30 March 2013; logging every 30 minutes), and a mean indoor temperature of 19.1°C (± 1.1 (SD)) was determined. From this point thermoregulation in terms of preventing heat loss was asserted manageable as the measured indoor temperature accorded to temperature indices for warm nights in free-range (Kruger and Shongwe, 2004). However, despite differences in BCS, no relationship with ration characteristics was observed.

***Intake activity and oral stereotypies***

Maximal time spans for intake activities are highly desirable in captive giraffes, as free-ranging animals spend large time spans with foraging and rumination (Pellew, 1984). With a mean of 30% of observation time being spent with forage and browse intake activity, present results resemble prior results on feed intake activity in captive giraffe (Koene and Visser, 1997). An increasing proportion of non-forage feeds led to less forage intake activity, and correspondingly, to lower forage intake which accords to the suggestion of a majorly energy-based intake regulation in the giraffes of the study. Less provision of non-forage feeds could emphasise the appetitive part of feeding (Koene, 1999), resulting in prolonged time spans for feed intake activity. A positive relation between dietary browse proportion and browse intake activity was confirmed, but correlations with the ingested non-forage proportion did not appear. Intake of browse was not lowered by high amounts of non-forage feeds, probably because browse was a “scarce asset”, being consumed with great acceptance and preferred overall (Koene and Visser, 1997; Hatt et al., 2005; Hummel et al., 2006b). In contrast to other forage, browse intake enabled engagement in species-typical, time-consuming food handling to the greatest possible extent. Browse intake activity took 11% of observation time even though browse intake only accounted for 7% of ration DM. In contrast, forage intake represented 50% of total DM intake, but captured only 19% of observation time.

Rumination took 23% of observation time, which was in line with previous findings in captivity (Koene and Visser, 1997) and close to free-range (29% of 24 hours; Pellew, 1984), but increasing forage proportion or intake activity did not result in increasing rumination as determined by Baxter and Plowman (2001). Especially regarding rumination it must be considered that preconditions in other studies differ as they mostly refer to intensive, long-term observation of single animals. Present data were detected under controlled conditions and in large quantity, but during very limited periods of time.

Restrictive feeding and foraging opportunities were described as sources of stress in captivity (Morgan and Tromborg, 2007). For captive giraffes, most frequently oral stereotypies occur (Bashaw et al., 2001), with repetitive licking on non-food objects (Bashaw et al., 2001) and repetitive tongue-swinging or -rolling (Sambraus, 1985). During 4.7% of observation time in the study oral stereotypies were observed, particularly in females. According to Hummel et al. (2006a), increasing proportions of concentrate or dietary ME content led to a more frequent appearance of oral stereotypies. Whereas DMI and feed intake activity were already limited on ground of energetic satiety, feeding of non-forage feeds also happened during few fixed times per day with little duration of employment. However, it cannot be ruled out that animals evolved stereotypies and may continue showing them even after change of feeding practice or a transfer between zoos, as stereotypies increasingly appeared with increasing age ($p < 0.001$) and primarily in single animals. The evaluation of oral stereotypies in groups of giraffes is affected by uncertainty and stereotypic behavior is known to “mature” (Mason, 1991), thus hardly suppressible if accustomed once. Nevertheless, a maximisation of feed intake activity will minimise potential spare time in which undesired replacement activities occur in captive giraffes.

## CONCLUSIONS

During 18 documentation periods in giraffe facilities of twelve German zoos, rations differed regarding proportions and chemical composition resulting in various grades of concordance to feeding recommendations. The estimated DMI and MEI were in line with prior data and sufficient to cover ME requirements. Regarding a negative relation of dietary ME content with DMI, feed intake was primarily regulated from energetic satiety and not on grounds of physical properties of feed. Consequently, the giraffes ingested as much food as qualitatively, but not quantitatively possible, even though forage was provided for *ad libitum* intake. These findings were also relevant in terms of behaviour, as a desirably high duration of feed intake activity and an effective prevention of oral stereotypies in captive giraffes was mostly possible with rations short in high-energy non-forage feeds. A negative relation of the produce proportion to DMI led to the assumption of certain acidotic conditions in the giraffes, as sugar-rich feeds easily lead to hyperacidic conditions in the rumen. The WAPS revealed a limited capacity of the giraffes to comminute their feed in captivity, but the WAPS was not meaningful to indicate different suitability of feeding among facilities. Content of $ADIA_{Faeces}$ was similar to values in free-ranging individuals and not related to $ADIA_{Feed}$; therefore, rations did not mandatorily lead to excessive tooth wear. Body condition was overall acceptable with some animals tending to slimness. The capacity of self-regulation of DMI and MEI with intake of good quality forage provided for *ad libitum* intake may work more reliable in giraffes than widely expected and shown for other browsing species. Basic requirement for increasing forage intake was the reduction of amounts of high-energy feeds in rations to fill the gap between qualitative and quantitative feed intake.

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## CHAPTER 6

# General conclusions

The focus of this thesis was to evaluate variation in current giraffe feeding practice in zoos and the potential impact of different rations on digestive physiology and behaviour, in consideration of particularly high demands of browsing compared to grazing ruminants on their nutrition in captivity. Browse as preferred and convenient forage is scarcely available for facilities and considerable differences between naturally foraged feed and rations in captivity can lead to physiological and behavioural conflicts. Subdivided in three sections, the thesis consists of information on feeding practice in European zoos gained in a survey and of further investigations on the quality of feedstuffs and the potential impact of ration composition on variables in giraffes, based on self-generated data from twelve German zoos.

**Comparability of data sources**

As assumed the results for ration composition in European zoos showed concordance with the results quantified for twelve German zoos. Dietary proportions were largely similar, with rations estimated from the survey consisting of 59% forage, 39% concentrate and 2% produce in ration DM (year-round median) and the data from German zoos resulting in rations of 57% forage, 39% concentrate and 4% produce (year-round mean). Slight variation became obvious regarding the percentage of zoos using specific forage and non-forage feeds (Table 24). Nevertheless, the results for EEP zoos were in line with the results gained from documentation periods in twelve German zoos. Consequently, considerations on ration composition and quality, DMI and physiological occurrences based on Chapter 4 and 5 were asserted to be applicable to the results from European zoos as described in Chapter 3.

**Table 24.** Comparison of information on usage of feedstuffs (in % of zoos) gained from a survey in member zoos of the European Endangered Species Program of the giraffe and during documentation periods in giraffe facilities of twelve German zoos

| | Survey (81 European zoos) | Own documentation (12 German zoos) |
|---|---|---|
| Forage | | |
| Lucerne hay | 89 | 92 |
| Grass or grass-clover hay | 29 | 8 |
| Fresh lucerne, grasses or mixtures | 44 | 42 |
| Further fresh forage | 10 | 16 |
| Browse (trees and branches) summer | 96 | 100 |
| Browse (trees and branches) winter | 86 | 67 |
| Preserved browse | 47 | 33 |
| Non-forage feeds | | |
| Compound feed | 96 | 92 |
| Dehydrated lucerne pellets | 30 | 67 |
| Pelleted browse-based product | 11 | 25 |
| Energy-rich cereal grain products | 28 | 58 |
| Fibre-rich cereal grain products | 23 | 42 |
| Soya-bean meal (solvent-extracted) | 9 | 50 |
| Sugar beet pulp | 19 | 58 |
| Produce | 85 | 92 |

**Concordance of feeding practice with recommendations**

As hypothesised, the results revealed obvious variation in giraffe feeding practice regarding ingredient composition of rations. The assumption that a considerable level of tradition and uncertainty influences giraffe feeding practice despite available feeding recommendations was confirmed. However, compared to prior studies (Hummel et al., 2006c; Sullivan et al., 2010) improvement was noticeable, especially regarding forage feeding with less zoos using grass hay, but more providing fresh browse as trees and branches. Lucerne hay showed an overall desirable quality and a similar chemical composition to browse, especially regarding fibre fractions. The suitability of lucerne hay as good compromise forage source for giraffes was thus accredited, and fortunately, almost every facility provided it for *ad libitum* intake. However, more attention must be paid on the protein delivering capacity of lucerne hay, as it likely contributed high amounts of protein to the rations. Consequently, lucerne hay should not only be valued as structural fibre-delivering forage, but also as protein source.

Desirable trends were likewise visible with the feeding of concentrates. Almost all zoos fed some compound feed. Regarding chemical composition and fermentative behaviour, an overall balance of compound feeds was observed and a high extent of safety in nutrient supply and compatibility was expectable. However, prominence of tradition and suboptimal planning of quantities was particularly noticeable with the feeding of non-forage feeds. Primarily zoos from Eastern European regions exceeded recommended proportions of concentrates, but likewise among German zoos the variation was substantial. Traditional feedstuffs like grain-based products were widely preferred over recommended products like dehydrated lucerne pellets or sugar beet pulp, even though the higher suitability of the latter products was re-accredited. Regarding prior studies on advantages of sugar beet pulp as energy-delivering feed (Van Soest et al., 1991; Hummel et al., 2006a; Hummel et al., 2006b), reasons for a limited ‘human acceptance’ of sugar beet pulp as high-energy feed for giraffes remained questionable.

Eighty-five percent of the zoos stated to feed fruits and vegetables, thus produce is still part and parcel in the nutrition of captive giraffes, even though not recommended or necessary from a nutritional point of view. Well-known disadvantageous fermentation characteristics and a potential contribution to unphysiological conditions in the rumen (Hummel et al., 2006a; Odongo et al., 2006) were confirmed in this study. From personal experience, the preparation of produce is also labour-intensive and its use is rather inefficient, as approximately 90% of the costs are allocable to pure water. Most important, due to negative effects of increasing produce proportions on feed intake in captive giraffe in this study, the necessity of feeding fruits and vegetables is put in serious question, and produce feeding cannot be recommended.

**Impact of practical feeding on captive giraffes**

The potential consequences of giraffe nutrition were identified through animal variables which can give evidence on lack of suitability of rations or feeds. The BCS, WAPS and content of $ADIA_{Faeces}$ were not related to composition or quality of the presently analysed rations, but results were of particular interest with regard to feed intake. The DMI showed a significant negative relation to the dietary ME content; high contents of ME in the ration resulted in a decreasing DMI. Following established explanations of feed intake regulation in ruminants (Conrad, 1966; Van Soest, 1994), intake was obviously limited due to an energetic satiety prior to limitation due to gut capacity. Giraffes in Europe frequently received portions of concentrate feed which likely satisfied energy requirements and indicated feed intake limitation at the expense of forage intake, resulting in low dietary forage proportions. As the

MEI in the giraffes was higher with rations high in forage, the capacity of giraffes for intake of good quality lucerne hay must not be underestimated. Due to structural and chemical differences, intake, comminution and digestion of lucerne hay may not be expectable in a similar quantity and effectivity compared to browse. However, the capacity to ingest lucerne hay was hardly exhausted in the giraffes of the study. The dietary forage proportion was also closely related to feed intake activity. Consumption of high amounts of forage led to a high proportion of time being spent with feed intake activity and less time being spent with oral stereotypies. Consequently, high ingested forage proportions were sufficient to minimise the risk of undesired behaviour in giraffes.

**Quality of data sources**

Regarding a response rate of 53%, a notably high representativeness of information on giraffe nutrition in European zoos was given with the survey. However, ration composition was calculated without information on amounts of left-over feeds, assuming the complete intake of given amounts of non-forage feeds as done so by Hummel et al. (2006c). From experience, the acceptance of concentrate feeds and produce is rather high, giving sufficient reason to estimate dietary proportions based on information on provided amounts of non-forage feeds. The potential DMI in the giraffes was calculated with consideration of particular demands due to performance, based on values gained from feed intake documentation as described in Chapter 5. From this point, the DMI in the groups of giraffes was presumably estimated with higher accuracy than if predicted on maintenance requirement only. However, estimation could not be based on actual BW, as very few zoos in Europe own scales for weight documentation and BW needed to be derived from available BW gain curves.

The generated data from 18 documentation periods in German zoos are novel and unique, as information on ration composition, feed intake and animal variables in captive giraffes is scarce in similar extent and detail. The execution of documentation periods by one person in rapid succession minimised environmental effects during acquisition and increased comparability of data, but again, the calculation of DMI in groups of giraffes would have worked with higher accuracy, if actual BW were available. Unfortunately, for 90% of the giraffes BW needed to be estimated during body condition scoring in intervals of 25 kg. The accuracy of prediction was certainly higher than relied on BW gain curves, but nevertheless flawed with some uncertainty. Finally, the discrepancy between quality and quantity of data in studies on zoo animals was of relevance also in the present study.

**Conclusions and outlook**

Almost ten years since the EEP published husbandry guidelines including feeding recommendations, a multitude of member zoos does, to a greater or lesser extent, not follow suggestions on a preferably suitable nutrition of captive giraffes. However, present feeding recommendations for captive giraffes were confirmed. Rations based on lucerne hay and supplied with much browse and limited amounts of suitable non-forage feeds remains the method of choice in feeding captive giraffes. To complement rations with energy and additional fibre, compound feeds, dehydrated lucerne pellets and sugar beet pulp remain recommendable as most suitable non-forage feeds and should be given priority to starch- or sugar-based products. The provision of forage for *ad libitum* intake enables a desirably high intake of forage. However, this is not alone effective, as the provision of non-forage feeds served as key moment in feed intake regulation of captive giraffes. As energetic satiety prevented the animals from ingesting preferably large amounts of forage, the adjustment of amounts of concentrate feeds was assessed as precondition to realise and ensure high forage intake. Doubts on sufficient energy supply may be resolved by the finding that giraffes in this study realised a particularly high energy intake when receiving smaller concentrate portions.

It remains questionable how the acceptance of feeding recommendations is increasable among zoos. The level of interest in aspects of giraffe nutrition is high, but a reprise or extensive communication was not fully effective so far. It may not be the feeding recommendations themselves, but their feasibility that is put into question. Potentially higher financial pressure and workload are frequently associated with changes of feeding practice. Prospect of saved costs in terms of discontinued produce feeding or less wastage of concentrate feeds should be clearer communicated and suggestions on a mandatorily higher workload due to revisions of feeding practice must be mitigated. Ultimately, it is the ‘human acceptance’ that decides on desirable and useful changes in giraffe feeding practice among European zoos.

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# APPENDIX

## AI. Questionnaire as send to the member zoos of the European Endangered Species Program of the giraffe

**Giraffe Nutrition in Zoos**

Survey in the context of a PhD-project at the University of Bonn about feeding captive giraffes

In accordance with the EEP stud book coordination
(Joerg Jebram, Zoom Erlebniswelt Gelsenkirchen, Germany)

Please give information on your current regular feeding practice in summer and winter.
Feel free to quantify feed supply for the whole group.
If possible, use units like kg or litres for your specifications and weigh/estimate weight of feedstuffs in original condition (e.g. unsoaked beet pulp).
For further information or questions do not hesitate to contact:
**Isabel Gussek,** [redacted]
Please return this survey in your preferred way by mail, fax or post until 31 August 2013. For possible call back I would like to contact you by phone.

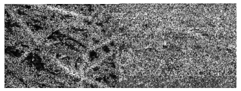
**General information**

| | |
|---|---|
| Institution (name) | |
| Person responding to survey (name, position) | |
| Contact details for further enquiry (phone, mail) | |
| Age (date of birth) and sex of giraffes | |
| Subspecies | |

## **AI.** Continued

### A. Nutrition in summer

**A1. Hay and fresh green**



Ad libitum and/or estimated amount in kg

| | | | | |
|---|---|---|---|---|
| O Lucerne hay | O ad libitum | O kg ……… | O per day | O per week |
| O Fresh lucerne | O ad libitum | O kg ……… | O per day | O per week |
| O Grass hay | O ad libitum | O kg …….... | O per day | O per week |
| O Fresh grass | O ad libitum | O kg ……… | O per day | O per week |

**A2. Browse**

Fresh browse (estimated amount in kg and/or number of branches (< 2m) or trees (> 2m))

| | | |
|---|---|---|
| O kg …………………………… | O per day | O per week |
| O branches (< 2m) …………….. | O per day | O per week |
| O trees (> 2m) …………………. | O per day | O per week |

Mainly provided types of fresh browse

O Birch O Willow O Oak O Ash O Robinia

O Hazelnut O Beech O ……………….. O ………………….

Dried browse (weighed or estimated amount in kg or litres)

O kg …………… O litres………… O per day O per week

Mainly provided types of dried browse

O Raspberry O Blackberry O Mixed berry leaves O Robinia

O ……………………………….. O ……………………………….

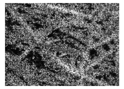
Further peculiarities concerning roughage and browse feeding during summer:

……………………………………………………………………….

……………………………………………………………………….

### B. Nutrition in winter

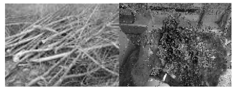
**B1. Hay**



Ad libitum and/or estimated amount in kg

| | | | | |
|---|---|---|---|---|
| O Lucerne hay | O ad libitum | O kg ……..... | O per day | O per week |
| O Grass hay | O ad libitum | O kg ………. | O per day | O per week |

**B2. Browse**



Branches without leaves (estimated amount in kg and/or number of branches (< 2m) or trees (> 2m))

| | | |
|---|---|---|
| O kg …………………………… | O per day | O per week |
| O branches (< 2m) …………….. | O per day | O per week |
| O trees (> 2m) …………………. | O per day | O per week |

Dried browse (weighed or estimated amount in kg or litres)

O kg …………… O litres………… O per day O per week

Mainly provided types of dried browse

O Raspberry O Blackberry O Mixed berry leaves O Robinia

O ……………………………….. O ………………………………..

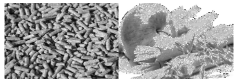
Further peculiarities concerning roughage and browse feeding during winter:

……………………………………………………………………….

……………………………………………………………………........

## **AI.** Continued

### A3. Concentrates and produce



Concentrates (weighed or estimated amount in kg or lit per day)

O kg O litres

O Zoopellets (for Herbivores/Ruminants) ……………........................

O Lucernepellets……………... O Lucernecobs……………………..

O Rolled oats ………………… O Oat flakes ……………………….

O Wheat flakes ………………. O Wheat bran………………………

O Maize ……………………… O Beet pulp ……………………........

O Soy…….. ………………….. O Linseed …………….……………

O ……………….…………………………………….…………………..

O ……………….…………………………………….…………………..

O ……………….…………………………………….…………………..

Produce (weighed or estimated amount in kg or litres (unchopped) per day)

O kg O litres

O Carrots………….. O Apples ………….. O Kohlrabi……………..

O Celery…………... O Cabbage………..... O Beetroot……………..

O Radish………….. O Salads…………… O Bananas……………...

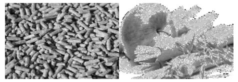
O Amount of additional fruits …………………………………………

O Amount of additional vegetables …………………………………...

Further peculiarities concerning concentrate and produce feeding during summer:

………………………………………………………………………………
………………………………………………………………………………
……………………………………………………

### B3. Concentrates and produce



Concentrates (weighed or estimated amount in kg or lit per day)

O kg O litres

O Zoopellets (for Herbivores/Ruminants) ……………...........................

O Lucernepellets……………... O Lucernecobs……………………..

O Rolled oats ………………… O Oat flakes ……………………….

O Wheat flakes ………………. O Wheat bran………………………

O Maize ……………………… O Beet pulp ……………………........

O Soy ………………….. O Linseed …………….……………

O ……………….…………………………………….……………………

O ……………….…………………………………….……………………

O ……………….…………………………………….……………………

Produce (weighed or estimated amount in kg or litres (unchopped) per day)

O kg O litres

O Carrots………….. O Apples ………….. O Kohlrabi……………..

O Celery…………... O Cabbage………..... O Beetroot……………..

O Radish………….. O Salads…………… O Bananas……………...

O Amount of additional fruits …………………………………………

O Amount of additional vegetables …………………………………...

Further peculiarities concerning concentrate and produce feeding during winter:

………………………………………………………………………………
………………………………………………………………………………
…………………………………………………………

**AI.** Continued

### C. Additional questions

#### C1. Hay

Presentation of lucerne hay/grass hay

O Filling racks with fresh material per day

| | | | | |
|---|---|---|---|---|
| Summer: | Indoor | O One time | O Two times | O > two times |
| | Outdoor | O One time | O Two times | O > two times |
| Winter: | Indoor | O One time | O Two times | O > two times |
| | Outdoor | O One time | O Two times | O > two times |

O Re-fluffing of material per day

| | | | | |
|---|---|---|---|---|
| Summer: | Indoor | O One time | O Two times | O > two times |
| | Outdoor | O One time | O Two times | O > two times |
| Winter: | Indoor | O One time | O Two times | O > two times |
| | Outdoor | O One time | O Two times | O > two times |

Provenance of lucerne/grass hay (region and/or provider) ………………………………………………………………………….......................

#### C2. Concentrates and produce

Feeding of concentrates

| | | | |
|---|---|---|---|
| Summer: | O Morning | O Noon | O Afternoon/evening |
| Winter: | O Morning | O Noon | O Afternoon/evening |

Feeding of produce

| | | | |
|---|---|---|---|
| Summer: | O Morning | O Noon | O Afternoon/evening |
| Winter: | O Morning | O Noon | O Afternoon/evening |

Provider and/or product labelling of used pelleted feeds

O Lucernepellets/-cobs ………………………….........................................................................................................................................

O Zoopellets (Herbivores/Ruminants) ……………………………………………………………………………….....................................

O Beet pulp products ………………………………………………..............................................................................................................

O ………………………………………………………………………..........................................................................................................

#### C3. Additives and water

Used additives

O Selenium   O Reformat   O Feed lime   O Vitamins   O Mineral lick

O ……………………………………………………   O……………………………………………………

Water access

| | | |
|---|---|---|
| O Indoor | O with self-drinkers | O with bucket or basin |
| O Outdoor | O with self-drinkers | O with bucket or basin |

**Thank you for your cooperation and kind support**

**AII.** Content of ME (MJ/kg DM), CP, ash, CF and fibre fractions (all in g/kg DM), estimated GP rate (c; %/h) and maximal GP (a + b; ml/200 mg DM) for the samples of browse leaves and browse bark, sorted according to type and date of supply (month/year)

| | | ME | CP | Ash | CF | aNDFom | ADFom | ADL | c | a + b |
|---|---|---|---|---|---|---|---|---|---|---|
| Birch leaves | 07/2012 | 7.5 | 174 | 49.4 | 67.9 | 499 | 371 | 220 | 5.4 | 26.3 |
| | 09/2012 | 7.4 | 157 | 59.9 | 86.0 | 432 | 274 | 172 | 4.4 | 24.5 |
| | 05/2013 | 8.7 | 184 | 37.4 | 92.1 | 435 | 280 | 199 | 4.4 | 26.5 |
| | 08/2013 | 7.7 | 122 | 35.3 | 67.0 | 485 | 396 | 243 | 5.8 | 29.1 |
| | Mean (± SD) | 7.8 (0.6) | 159 (27) | 45.5 (11) | 78.3 (13) | 463 (34) | 330 (62) | 209 (30) | 5.0 (0.7) | 26.6 (1.9) |
| Birch bark | 07/2012 | 5.4 | 38.9 | 41.4 | 21.1 | 630 | 548 | 305 | 13.4 | 19.7 |
| | 07/2012 | 5.0 | 40.3 | 37.3 | 23.1 | 668 | 538 | 308 | 17.8 | 16.2 |
| | 09/2012 | 5.3 | 41.9 | 31.5 | 23.3 | 613 | 545 | 314 | 11.6 | 19.6 |
| | 05/2013 | 5.4 | 35.0 | 18.8 | 26.7 | 679 | 581 | 282 | 12.2 | 19.1 |
| | 08/2013 | 6.3 | 40.7 | 29.7 | 46.9 | 576 | 516 | 307 | 12.6 | 23.0 |
| | Mean (± SD) | 5.5 (0.5) | 39.4 (2.7) | 31.7 (8.6) | 28.2 (11) | 633 (42) | 546 (23) | 303 (12) | 13.5 (2.5) | 19.5 (2.4) |
| Hazelnut leaves | 05/2012 | 7.6 | 174 | 89.8 | 24.7 | 528 | 286 | 124 | 5.6 | 34.8 |
| | 08/2012 | 7.2 | 125 | 85.6 | 29.2 | 456 | 301 | 115 | 4.7 | 37.7 |
| | 06/2013 | 7.4 | 111 | 78.8 | 18.5 | 455 | 265 | 115 | 5.7 | 38.8 |
| | 06/2012 | 7.8 | 165 | 83.3 | 31.9 | 526 | 302 | 112 | 4.8 | 38.7 |
| | 08/2013 | 6.6 | 111 | 54.8 | 20.6 | 512 | 337 | 158 | 4.7 | 32.6 |
| | Mean (± SD) | 7.3 (0.5) | 137 (30) | 78.5 (14) | 25.0 (5.6) | 495 (37) | 298 (26) | 125 (19) | 5.1 (0.5) | 36.5 (2.7) |
| Hazelnut bark | 05/2102 | 6.3 | 75.1 | 49.4 | 15.9 | 611 | 531 | 265 | 7.4 | 29.1 |
| | 06/2012 | 6.0 | 71.7 | 59.1 | 15.5 | 629 | 537 | 265 | 5.4 | 28.3 |
| | 06/2013 | 6.5 | 51.0 | 52.3 | 15.6 | 578 | 544 | 265 | 6.5 | 30.3 |
| | 08/2012 | 6.0 | 54.7 | 58.9 | 15.8 | 595 | 531 | 260 | 6.3 | 28.2 |
| | 08/2103 | 6.2 | 68.2 | 42.5 | 21.3 | 592 | 535 | 314 | 7.2 | 27.9 |
| | Mean (± SD) | 6.2 (0.2) | 64.1 (11) | 52.4 (7.0) | 16.8 (2.5) | 601 (20) | 536 (5.4) | 274 (23) | 6.6 (0.8) | 28.8 (1.0) |

**AII.** Continued

| | | ME | CP | Ash | CF | aNDFom | ADFom | ADL | c | a + b |
|---|---|---|---|---|---|---|---|---|---|---|
| Sallow leaves | 06/2012 | 8.2 | 170 | 76.7 | 37.1 | 360 | 336 | 158 | 6.6 | 37.7 |
| | 08/2012 | 8.4 | 124 | 103 | 41.9 | 327 | 264 | 134 | 7.3 | 39.6 |
| | 09/2012 | 6.7 | 150 | 54.1 | 26.6 | 453 | 384 | 227 | 4.6 | 30.6 |
| | 09/2012 | 8.3 | 127 | 97.2 | 41.8 | 454 | 373 | 201 | 8.3 | 38.2 |
| | 06/2013 | 7.8 | 120 | 54.2 | 29.1 | 397 | 379 | 232 | 6.3 | 39.2 |
| | Mean (± SD) | 7.9 (0.7) | 138 (21) | 77.0 (23) | 35.3 (7.1) | 398 (56) | 347 (50) | 190 (43) | 6.6 (1.4) | 37.1 (3.7) |
| Sallow bark | 06/2012 | 7.4 | 60.7 | 72.9 | 38.6 | 508 | 485 | 165 | 4.2 | 43.3 |
| | 09/2012 | 6.8 | 66.5 | 54.4 | 30.3 | 473 | 494 | 257 | 5.6 | 35.6 |
| | 09/2012 | 7.4 | 48.8 | 75.3 | 27.1 | 443 | 435 | 173 | 4.9 | 43.9 |
| | 01/2013 | 8.5 | 115 | 65.4 | 26.1 | 349 | 313 | 136 | 5.9 | 45.9 |
| | 06/2013 | 6.8 | 45.2 | 72.2 | 27.9 | 534 | 534 | 275 | 4.8 | 38.4 |
| | Mean (± SD) | 7.4 (0.7) | 67.2 (28) | 68.0 (8.5) | 30.0 (5.1) | 461 (72) | 452 (85) | 201 (61) | 5.1 (0.7) | 41.4 (4.3) |
| Oak leaves | 06/2012 | 8.1 | 210 | 46.4 | 37.9 | 541 | 330 | 130 | 4.4 | 37.9 |
| | 05/2013 | 9.8 | 213 | 42.1 | 37.7 | 353 | 230 | 84.0 | 7.8 | 45.9 |
| | 06/2013 | 7.0 | 150 | 41.6 | 13.1 | 430 | 304 | 153 | 4.5 | 34.7 |
| | 07/2103 | 6.3 | 161 | 62.1 | 17.9 | 536 | 382 | 195 | 3.7 | 29.7 |
| | 08/2103 | 6.8 | 131 | 57.8 | 35.5 | 422 | 299 | 143 | 4.5 | 30.0 |
| | Mean (± SD) | 7.6 (1.4) | 173 (37) | 50.0 (9.4) | 28.4 (12) | 456 (81) | 309 (55) | 141 (40) | 5.0 (1.6) | 35.7 (6.7) |
| Oak bark | 06/2012 | 6.0 | 59.6 | 36.8 | 17.4 | 604 | 514 | 247 | 6.2 | 27.5 |
| | 01/2013 | 5.8 | 83.9 | 67.0 | 24.7 | 567 | 434 | 243 | 6.0 | 24.3 |
| | 05/2013 | 5.3 | 50.7 | 39.0 | 10.9 | 648 | 573 | 314 | 7.3 | 23.2 |
| | 06/2013 | 6.2 | 56.0 | 66.3 | 4.92 | 564 | 497 | 222 | 4.5 | 34.7 |
| | 07/2103 | 5.2 | 54.5 | 56.3 | 12.9 | 579 | 567 | 294 | 5.7 | 22.0 |
| | Mean (± SD) | 5.7 (0.4) | 60.9 (13) | 53.1 (15) | 14.2 (7.4) | 592 (35) | 517 (57) | 264 (38) | 5.9 (1.0) | 26.4 (5.1) |

**AII.** Continued

| | | ME | CP | Ash | CF | aNDFom | ADFom | ADL | c | a + b |
|---|---|---|---|---|---|---|---|---|---|---|
| Ash leaves | 06/2012 | 9.5 | 152 | 107 | 29.4 | 416 | 258 | 89.0 | 7.8 | 48.3 |
| | 08/2012 | 8.4 | 173 | 113 | 33.3 | 439 | 325 | 100 | 6.2 | 40.7 |
| | 08/2013 | 8.6 | 125 | 116 | 36.4 | 420 | 283 | 103 | 7.2 | 43.0 |
| | Mean (± SD) | 8.9 (0.6) | 150 (24) | 112 (4.6) | 33.0 (3.5) | 425 (12) | 289 (34) | 97.3 (7.4) | 7.1 (0.8) | 44.0 (3.9) |
| Ash bark | 06/2012 | 8.3 | 47.0 | 79.7 | 21.3 | 427 | 375 | 93.7 | 5.4 | 49.1 |
| | 08/2013 | 8.7 | 48.8 | 59.4 | 23.9 | 426 | 378 | 116 | 5.5 | 49.9 |
| | Mean (± SD) | 8.5 (0.2) | 47.9 (1.3) | 69.6 (14) | 22.6 (1.8) | 427 (0.7) | 377 (2.1) | 105 (16) | 5.5 (0.1) | 49.5 (0.6) |
| Beech leaves | 08/2012 | 6.4 | 122 | 43.0 | 25.2 | 473 | 350 | 178 | 3.7 | 31.7 |
| | 02/2013 | 5.7 | 108 | 37.0 | 18.5 | 644 | 484 | 194 | 4.5 | 25.6 |
| | 05/2013 | 8.2 | 171 | 43.8 | 26.3 | 415 | 296 | 111 | 5.8 | 39.2 |
| | 07/2013 | 5.4 | 120 | 61.8 | 25.1 | 602 | 461 | 220 | 3.3 | 22.0 |
| | 08/2013 | 8.0 | 134 | 77.8 | 37.8 | 401 | 249 | 77.0 | 6.1 | 37.6 |
| | Mean (± SD) | 6.7 (1.3) | 131 (24) | 52.7 (17) | 26.6 (7.0) | 507 (110) | 368 (102) | 156 (60) | 4.7 (1.2) | 31.2 (7.5) |
| Beech bark | 05/2013 | 6.1 | 53.3 | 50.7 | 12.8 | 628 | 545 | 256 | 7.4 | 27.9 |
| | 07/2013 | 5.9 | 38.0 | 69.7 | 12.9 | 635 | 564 | 268 | 8.6 | 26.5 |
| | Mean (± SD) | 6.0 (0.1) | 45.7 (11) | 60.2 (13) | 12.9 (0.1) | 632 (5.0) | 555 (13) | 262 (8.5) | 8.0 (0.9) | 27.2 (1.0) |
| Hornbeam leaves | 05/2012 | 8.3 | 131 | 39.1 | 18.5 | 343 | 207 | 65.2 | 5.9 | 41.6 |
| | 08/2013 | 5.8 | 114 | 45.5 | 15.1 | 569 | 448 | 234 | 3.8 | 26.0 |
| | Mean (± SD) | 7.0 (1.7) | 122 (12) | 42.3 (4.5) | 16.8 (2.4) | 456 (160) | 328 (170) | 150 (119) | 4.8 (1.5) | 33.8 (11) |
| Hornbeam bark | 05/2012 | 6.2 | 60.0 | 86.0 | 7.14 | 620 | 544 | 249 | n.a. | n.a. |
| | 08/2013 | 6.2 | 38.8 | 37.2 | 25.9 | 632 | 555 | 281 | 8.0 | 27.7 |
| | Mean (± SD) | 6.2 (0.02) | 49.4 (15) | 61.6 (35) | 16.5 (13) | 626 (8.5) | 550 (7.8) | 265 (23) | 8.0 | 27.7 |
| Robinia leaves | 08/2012 | 7.5 | 190 | 92.0 | 31.0 | 384 | 302 | 135 | 4.7 | 35.5 |
| | 08/2013 | 8.0 | 153 | 98.2 | 35.9 | 466 | 429 | 207 | 7.0 | 36.5 |
| | Mean (± SD) | 7.7 (0.3) | 172 (26) | 95.1 (4.4) | 33.5 (3.5) | 425 (58) | 366 (90) | 171 (51) | 5.9 (1.6) | 36.0 (0.7) |

**AII.** Continued

| | | ME | CP | Ash | CF | aNDFom | ADFom | ADL | c | a + b |
|---|---|---|---|---|---|---|---|---|---|---|
| Robinia bark | 08/2012 | 8.1 | 146 | 78.2 | 21.4 | 527 | 440 | 150 | 6.1 | 41.7 |
| | 08/2013 | 6.5 | 138 | 100 | 21.9 | 574 | 454 | 193 | 4.2 | 30.1 |
| | Mean (± SD) | 7.3 (1.1) | 142 (5.7) | 89.1 (15) | 21.7 (0.4) | 550 (33) | 447 (9.9) | 172 (30) | 5.1 (1.3) | 35.9 (8.1) |
| Maple leaves | 08/2012 | 8.6 | 139 | 107 | 47.0 | 379 | 296 | 119 | 9.0 | 37.9 |
| | 08/2013 | 8.7 | 171 | 110 | 41.9 | 342 | 276 | 109 | 9.2 | 38.5 |
| | 08/2013 | 9.1 | 121 | 92.2 | 58.9 | 405 | 264 | 95.6 | 7.3 | 42.2 |
| | Mean (± SD) | 8.8 (0.2) | 144 (25) | 103 (9.5) | 49.3 (8.7) | 375 (32) | 279 (16) | 108 (12) | 8.5 (1.0) | 39.5 (2.3) |
| Maple bark | 08/2012 | 6.0 | 84.1 | 122 | 158 | 607 | 539 | 284 | 6.7 | 25.7 |
| | 08/2013 | 8.1 | 54.0 | 60.6 | 36.8 | 466 | 429 | 207 | 8.1 | 41.5 |
| | 08/2013 | 7.1 | 76.4 | 67.5 | 13.6 | 571 | 522 | 239 | 10.9 | 33.3 |
| | Mean (± SD) | 7.1 (1.1) | 71.5 (16) | 83.4 (34) | 69.5 (78) | 548 (73) | 497 (59) | 243 (39) | 8.6 (2.1) | 33.5 (7.9) |
| Linden leaves | 07/2013 | 8.8 | 126 | 114 | 41.2 | 462 | 274 | 133 | 7.4 | 42.4 |
| | 08/2013 | 8.5 | 139 | 135 | 54.2 | 501 | 256 | 89.3 | 6.9 | 37.9 |
| | Mean (± SD) | 8.6 (0.1) | 133 (9.2) | 125 (15) | 47.7 (9.2) | 482 (28) | 265 (13) | 111 (31) | 7.2 (0.3) | 40.1 (3.2) |
| Linden bark | 07/2013 | 9.4 | 44.7 | 139 | 74.2 | 503 | 359 | 188 | 8.7 | 36.1 |
| | 08/2013 | 7.7 | 43.7 | 82.3 | 35.9 | 614 | 477 | 170 | 7.8 | 39.0 |
| | Mean (± SD) | 8.6 (1.2) | 44.2 (0.7) | 111 (40) | 55.1 (27) | 559 (78) | 418 (83) | 179 (13) | 8.2 (0.6) | 37.6 (2.1) |
| Red oak leaves | 02/2013 | 8.3 | 164 | 39.0 | 30.0 | 460 | 294 | 131 | 5.6 | 41.8 |
| | 06/2013 | 8.9 | 140 | 57.2 | 35.3 | 371 | 290 | 118 | 10.6 | 41.2 |
| | Mean (± SD) | 8.6 (0.4) | 152 (17) | 48.1 (13) | 32.7 (3.8) | 416 (63) | 292 (2.8) | 125 (9.2) | 8.1 (3.5) | 41.5 (0.4) |
| Cornus leaves | 08/2012 | 9.1 | 136 | 112 | 45.5 | 213 | 157 | 46.1 | 7.6 | 42.9 |
| Bamboo | 08/2012 | 7.7 | 119 | 59.2 | 26.2 | 731 | 374 | 70.7 | 4.4 | 45.7 |
| Blackberry leaves | 01/2013 | 9.2 | 163 | 63.1 | 41.7 | 344 | 223 | 71.4 | 6.6 | 44.5 |
| Read oak bark | 06/2013 | 6.9 | 53.5 | 55.3 | 12.3 | 600 | 566 | 220 | 9.8 | 32.9 |
| Elm leaves | 07/2013 | 10.3 | 221 | 115 | 43.0 | 462 | 255 | 101 | 10.6 | 46.4 |
| Elm bark | 07/2013 | 8.9 | 81.0 | 66.2 | 18.7 | 617 | 520 | 141 | 6.3 | 51.9 |

**AII.** Continued

ME = metabolisable energy; CP = crude protein; CF = crude fat; aNDFom = neutral detergent fibre, assayed with heat stable amylase, expressed exclusive of residual ash; ADFom = acid detergent fibre, expressed exclusive of residual ash, ADL = acid detergent lignin; n.a. = not available; SD = standard deviation

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Gussek, I., Südekum, K.-H., Hummel, J.: Influence of composition and nutritional quality of diets for giraffes (*Giraffa camelopardalis*) on dry matter intake and feed intake activity. (Vortrag)

Gussek, I., Südekum, K.-H., Hummel, J.: Composition and quality of diets for giraffes (*Giraffa camelopardalis*) in twelve German zoos. (Poster)

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Gussek, I., Hummel, J., Südekum, K.-H.: Getrenntes und sequentielles Verfahren zur Analyse der Säure-Detergenzien-Faser in pektinhaltigen Futtermitteln. (Vortrag)

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